CA1
DTC800
84
F71
C.2

Library and Information Centre / Centre de Documentation (GSLA)
RECEIVED - REÇU LE
SEP 30 1988
Transport Canada / Transports Can

CA1
DTC800-
84
F71
(c)

389069

COPY NO. _____

41.D

TP 6727E RAX-000-161

FUTURE AIRCRAFT CONCEPTS

An Investigation of the feasibility of an All-wing Passenger Transport

Prepared for: Transportation Development Centre, Transport Canada

April 1984

CANADAIR LIMITED REGARDS THIS INFORMATION TO THE GOVERNMENT IN CONFIDENCE. WE BELIEVE THIS IS PROPRIETARY, CONFIDENTIAL INFORMATION WHICH WE CONSIDER EXCLUDED FROM THE APPLICATION OF THE ACCESS TO INFORMATION ACT AND MAY ALSO BE A TRADE SECRET OF OUR COMPANY. PUBLIC RELEASE OF THIS INFORMATION WOULD BE HARMFUL TO CANADAIR LIMITED IF THE HEAD OF ANY GOVERNMENT DEPARTMENT OR AGENCY INTENDS TO DISCLOSE THIS INFORMATION OR PART THEREOF, WE REQUEST THAT WRITTEN NOTICE BE GIVEN TO CANADAIR LIMITED, ATTENTION: CORPORATE VICE PRESIDENT ADMINISTRATION AND LEGAL, P.O. BOX 6087 MONTREAL, QUEBEC H3C 3G9.

THESE TECHNICAL DATA & THE DESIGNS DISCLOSED HEREIN ARE THE EXCLUSIVE PROPERTY OF CANADAIR LTD. OR MAY CONTAIN PROPRIETARY RIGHTS OF OTHERS & ARE NOT TO BE USED OR DISCLOSED TO OTHERS WITHOUT THE WRITTEN CONSENT OF CANADAIR LTD. THE RECIPIENT OF THIS DOCUMENT BY ITS RETENTION & USE AGREES TO HOLD IN CONFIDENCE THE TECHNICAL DATA AND DESIGNS CONTAINED HEREIN. THE RECIPIENT ALSO AGREES TO PERSONALLY PROPRIETARY & CONFIDENTIAL SUCH TECHNICAL DATA OR SUCH DESIGNS TO THE EXTENT THAT SUCH RIGHTS EXIST.

canadair

389068

89-06304/

D. 2489 REV. 1/84

COPY NO. _____

CANADAIR LIMITED IS PROVIDING THIS INFORMATION TO THE GOVERNMENT IN CONFIDENCE. WE BELIEVE THIS IS PROPRIETARY CONFIDENTIAL INFORMATION WHICH WE CONSIDER EXCLUDED FROM THE APPLICATION OF THE ACCESS TO INFORMATION ACT AND MAY ALSO BE A TRADE SECRET OF OUR COMPANY. PUBLIC RELEASE OF THIS INFORMATION WOULD BE HARMFUL TO CANADAIR LIMITED. IF THE HEAD OF ANY GOVERNMENT DEPARTMENT OR AGENCY INTENDS TO DISCLOSE THIS INFORMATION, OR PART THEREOF, WE REQUEST THAT WRITTEN NOTICE BE GIVEN TO CANADAIR LIMITED, ATTENTION: CORPORATE VICE-PRESIDENT ADMINISTRATION AND LEGAL, P.O. BOX 6087, MONTREAL, QUEBEC H3C 3G9.

THESE TECHNICAL DATA & THE DESIGNS DISCLOSED HEREIN ARE THE EXCLUSIVE PROPERTY OF CANADAIR LTD OR MAY CONTAIN PROPRIETARY RIGHTS OF OTHERS & ARE NOT TO BE USED OR DISCLOSED TO OTHERS WITHOUT THE WRITTEN CONSENT OF CANADAIR LTD. THE RECIPIENT OF THIS DOCUMENT, BY ITS RETENTION & USE, AGREES TO HOLD IN CONFIDENCE THE TECHNICAL DATA AND DESIGNS CONTAINED HEREIN. THE FOREGOING SHALL NOT APPLY TO PERSONS HAVING PROPRIETARY RIGHTS TO SUCH TECHNICAL DATA OR SUCH DESIGNS TO THE EXTENT THAT SUCH RIGHTS EXIST.

canadair

FUTURE AIRCRAFT CONCEPTS

AN INVESTIGATION OF THE FEASIBILITY

OF AN

ALL-WING PASSENGER TRANSPORT

RAX-000-161

PREPARED A.A. Powell — DATE 7th June 1984

p.p. P.H. Whyte

CHECKED A.A. Powell — 7th June 1984

APPROVED T.J. Hughes

REVISION LOG

REV. LETTER	DATE	REVISED BY	APPROVED BY	PAGES AFFECTED	REMOVED	ADDED	REMARKS
NC	April 84						

THIS REPORT CONTAINS 52 PAGES

The contents of this report reflect the views of the authors and do not necessarily reflect the official view or opinions of the Transportation Development Centre of Transport Canada.

Un sommaire français de ce rapport est inclus avant la Table des matières.

Transport Canada / Transports Canada
Development / Développement

REPORT DOCUMENTATION FORM

1. Transport Canada Report No.	2. TDC Project No.	3. Recipient's Catalogue No.
TP 6727E	4801	

4. Title and Subtitle	5. Report Date
Future Aircraft Concepts: an investigation of the feasibility of an all-wing passenger transport	April 1984
	6. Performing Organization Report No. RAX-000-161
7. Author(s) P.J.Whyte	8. Transport Canada File No. 1455-112-5
9. Performing Organization Name and Address Canadair Limited P.O.Box 6087 Montreal, Quebec	10. DSS File No. 14SD T8200-2-2529 11. DSS or Transport Canada Contract No.
12. Sponsoring Agency Name and Address Transportation Development Centre 200 Dorchester Blvd. West Suite 601, West Tower Montreal, Quebec H2Z 1X4	13. Type of Report and Period Covered 14. Sponsoring Agency Code
15. Supplementary Notes	16. TDC Project Officer B.Myers

17. Abstract

The purpose of the study described in this report is to establish whether an all-wing aircraft design could be significantly superior to a more conventional wing-body-tail design with the same level of technology.

The results of the study indicate that for a small commercial transport with a capacity of 70 passengers the conventional design is more efficient in terms of fuel used than an all-wing aircraft. A blended wing-body configuration can conceivably be more appealing in a large enough aircraft with more passengers, for which higher wing loadings and lift coefficients can be selected.

18. Key Words	19. Distribution Statement
all-wing, transport aircraft, fuel efficiency, direct operating cost	Limited numbers of copies available from the Transportation Development Centre

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price
Unclassified	Unclassified	52	

Transports Canada / Transport Canada
Développement / Development

FORMULE DOCUMENTAIRE DU RAPPORT

1. N° du rapport Transports Canada	2. N° de l'étude — CDT	3. N° de catalogue du destinataire
TP 6727E	4801	

4. Titre et sous-titre	5. Date du rapport
Future Aircraft Concepts: an investigation of the feasibility of an all-wing passenger transport	Avril 1984
	6. N° du rapport de l'organisme exécutant: RAX-000-161
7. Auteur(s): P.J. Thyte	8. N° de dossier Transports Canada: 1455-112-5
9. Nom et adresse de l'organisme exécutant: Canadair Limitée, C.P. 6037, Montréal, Québec	10. N° de dossier — ASC: 14SD T8200-3-2529
	11. N° de contrat — ASC ou Transports Canada
12. Nom et adresse de l'organisme parrain: Centre de développement des transports, 200 ouest, boul. Dorchester, Suite 601, tour ouest, Montréal, Québec H2Z 1X4	13. Genre de rapport et période visée
	14. Code de l'organisme parrain
15. Remarques additionnelles	16. Agent de projet — CDT: B. Myers

17. Resume

La présente étude de faisabilité a pour objet de déterminer si le concept d'un avion tout-aile pourrait être considérablement supérieur à celui d'un avion classique (voilure-fuselage-empennage) issue d'une technologie identique à celle de l'avion tout-aile. Les resultats obtenus révèlent que, dans le cas d'un petit avion commercial pouvant transporter 70 passagers, la configuration classique est plus efficace en termes de rendement énergétique et de coûts d'exploitation directs que la configuration tout-aile. De façon concevable la solution retenue peut-être avantageuse pour un avionassez gros transportant un plus grand nombre de passagers en offrant une charge alaire et un coefficient de portance plus élevés.

18. Mots-clés	19. Diffusion
all-wing, transport aircraft, fuel efficiency, direct operating cost	Le Centre de développment des transports dispose d'un nombre limité d'exemplaires.

20. Classification de sécurité (de ce rapport)	21. Classification de sécurité (de cette page)	22. Nombre de pages	23. Prix
non-classifié	non-classifié	52	

Canada

SUBJECT AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

ACKNOWLEDGEMENT

This work was performed during the period
1 October 1982 - 31 December 1983 (JN50560).
Funding was provided by the Transportation
Development Centre of Transport Canada.

SUBJECT
AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

SUMMARY

The purpose of the study described in this report is to establish whether an All-Wing aircraft design could be significantly superior to a more conventional wing-body-tail design with the same level of technology.

The conventional configuration selected is a 70 passenger aircraft, with a 2200 nautical miles range and a cruise Mach number of 0.80, designed for production in the early 1990's. An All-Wing aircraft is designed to the same specifications, using the same level of technology (composite primary structures, supercritical wing sections, high by-pass turbofans). It is found that in order to achieve the desired cabin floor area and volume, a pure all-wing configuration needs a very large wing area and is not viable. A Blended Wing-Body Configuration, retaining advantages of a pure All-Wing with a reduced wing area, is selected instead. After several iterations, an arrangement and viable structural concept for this layout are adopted and the performance and stability and control characteristics of the aircraft estimated.

The results of the study indicate that for a small commercial transport, with a capacity of 70 passengers, the conventional design is more efficient, in terms of fuel used and direct operating costs, than an all-wing aircraft. A blended wing-body configuration can conceivably be more appealing in a large enough aircraft, with more passengers, for which higher wing loadings and lift coefficients can be selected. For short missions, an unconventional configuration could then be superior to a conventional design.

SUBJECT
ETUDE DE FAISABILITE D'UN AVION DE TRANSPORT DE PASSAGERS TOUT-AILE

SOMMAIRE

La présente étude de faisabilité a pour objet de déterminer si le concept d'un avion tout-aile pourrait être considérablement supérieur à celui d'un avion classique (voilure-fuselage-empennage) issu d'une technologie identique à celle de l'avion tout-aile.

Dans l'étude, nous comparons un avion tout-aile et un avion de configuration classique, à 70 places, offrant une distance franchissable de 2 200 milles marins et une vitesse de croisière de 0,8 Mach, et dont la production est prévue pour le début des années 1990. L'avion tout-aile serait construit selon les mêmes spécifications et caractéristiques technologiques que l'avion classique: structures principales en matériaux composites, profil d'aile supercritique, turboréacteurs à double flux à taux de dilution élevé. L'étude démontre que l'avion tout-aile devrait avoir une surface alaire très grande, ce qui n'est pas viable, pour offrir le volume et la surface de plancher désirés dans la cabine. Par conséquent, nous avons retenu une solution mitoyenne: un avion tout-aile doté d'un fuselage court et d'une surface alaire moins grande. Au bout de plusieurs essais, nous avons réussi à mettre au point une configuration viable et à évaluer les performances, la stabilité et la navigabilité d'un tel avion.

Les résultats obtenus révèlent que, dans le cas d'un petit avion commercial pouvant transporter 70 passenger, la configuration classique est plus efficace en termes de rendement énergétique et de coûts d'exploitation directs que la configuration tout-aile. De façon concevable, la solution retenue peut être avantageuse pour un avion assez gros, transportant un plus grand nombre de passagers, en offrant une charge alaire, et un coefficient de portance plus élevés. En outre, une configuration futuriste tout-aile pourrait s'avérer supérieure à une configuration classique pour les trajets courts.

SUBJECT AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

TABLE OF CONTENTS

		PAGE
ACKNOWLEDGEMENT		v
NOTATION		ix
LIST OF FIGURES		xi
1.0	INTRODUCTION	1
2.0	DESIGN EVOLUTION	8
2.1	Planform Trade-Off Study	8
2.2	Initial All-Wing Configuration	11
2.3	Blended Wing-Body Configuration	12
2.4	Performance, Stability and Control	15
2.4.1	Performance	15
2.4.2	Stability and Control	18
3.0	DISCUSSION	21
4.0	CONCLUDING REMARKS	26
5.0	REFERENCES	27
TABLE		28
FIGURES		29
APPENDIX		44

SUBJECT AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

NOTATION

A	aspect ratio
ASNM	available seat - nautical miles
a	speed of sound
B	Breguet range parameter = $\frac{V}{sfc} \cdot \frac{L}{D}$
BT	block time
C_D	drag coefficient
C_{Dmin}	minimum drag coefficient
C_{Do}	zero lift drag coefficient ($\approx C_{Dmin}$)
C_L	lift coefficient
C_{Lopt}	lift coefficient for best lift - drag ratio = $\sqrt{\frac{C_{Do}}{K}}$
C_m	pitching moment coefficient
D	drag
D_p	parasite drag
DOC	direct operating cost
e	Oswald efficiency factor
FP	fuel price (1982 US $/US gallon)
~~S~~	fuel fraction = $\frac{W_{\text{~~S~~}}}{W}$
g	thrust lapse rate (function of altitude)
h	altitude
ICA	initial cruise altitude
C_{Dw}	wave drag coefficient

SUBJECT
AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

NOTATION

K	induced drag factor = $\frac{I}{\pi Ae}$
L	lift
$\frac{L}{D}$	lift - drag ratio
M	Mach number
M_d	drag divergence Mach number
R	range
S	wing reference area
SFC	engine installed specific fuel consumption
T	sea level static thrust at take-off
$\frac{T}{W}$	thrust - weight ratio
V	true airspeed
W	maximum take-off gross weight
W_f	weight of usable fuel
$\frac{W}{S}$	wing loading
Λ	sweep angle at quarter-chord
λ	taper ratio
σ	density ratio
ρ_0	sea level density, ISA conditions = 0.0023769 sl/ft^3
( )aw	all-wing configuration
( )conv	conventional wing-body-tail configuration
( ) cr	cruise condition

SUBJECT AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

LIST OF FIGURES

1. BASELINE CONVENTIONAL CONFIGURATION (Reference 1)
2. THE EFFECT OF SUPERCRITICAL WING TECHNOLOGY
3. ESTIMATED OVERALL FLYING WING DIMENSIONS
4. TYPICAL RESULTS OF PLANFORM TRADE-OFF STUDY
5. EFFECT OF WING PLANFORM ON FUEL USAGE
6. INITIAL ALL-WING CONFIGURATION
7. PASSENGER CABIN CROSS-SECTION
8. CENTRE SECTION PLAN VIEW AND INBOARD PROFILE
9. GENERAL ARRANGEMENT OF BLENDED WING-BODY CONFIGURATION
10. WEIGHT AND BALANCE DIAGRAM
11. LIFT-DRAG RATIO IN CRUISE versus INITIAL CRUISE ALTITUDE
12. FUEL FRACTION versus INITIAL CRUISE ALTITUDE
13. DIRECT OPERATING COST PARAMETER versus INITIAL CRUISE ALTITUDE
14. RELATIVE DIRECT OPERATING COST PER POUND OF MTOW FOR DIFFERENT RANGES

SUBJECT AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

1.0 INTRODUCTION

The concept of an all-wing aircraft is deceptively simple; eliminate the fuselage and empennage and carry the useful load within the aerodynamic contour of the wing itself. The all-wing aircraft thus, differs from the tail-less aircraft as pioneered by Alexander Lippisch[1], which has a distinct fuselage and vertical tail, but no horizontal tail. Intuitively, one might expect the all-wing aircraft to be superior both to the tail-less aircraft and today's conventional aircraft, because the parasite and interference drags associated with the presence of a fuselage and an empennage are eliminated. The purpose of this report is to present the results of an advanced design study of the feasibility of an all-wing aircraft configuration and to establish for the defined specification whether this design is superior to a conventional wing-body-tail design.

The conventional design selected as the baseline for comparison was generated during an earlier study of aircraft energy efficiency[2]. The general arrangement of this aircraft is presented in Figure 1. The technology is consistent with serial production in the early 1990's. This aircraft is designed to carry a payload of 70 passengers and luggage a distance of at least 2200 nautical miles, at a cruise Mach number of 0.80.

The requirement for serial production in the early 1990's places an upper limit on the technology level which can be incorporated into the design. In particular, a turbofan powerplant which either currently exists, or is in an advanced stage of development, must be employed because of the lead time typical of powerplant design and development. Consequently, the baseline conventional aircraft is powered by three CF-34 turbofans.

SUBJECT AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

This powerplant lags the current state-of-the-art in turbofan propulsion, having been in service in some form since the mid-1970's. Previous studies [3] have shown that, of all the technological advances which can be applied to future aircraft, it is advances in propulsion which will contribute most to improving energy efficiency. As a result, it was concluded in Reference 2 that, compared to existing aircraft, the improvement in energy efficiency predicted for the baseline conventional configuration would not be enough to justify its development. It should be noted that, in the case of much larger aircraft, improvements in propulsion system efficiency are currently receiving a great deal of attention, but to date there has not been any impact on smaller engines applicable to a 70-passenger transport.

Since a conventional aircraft configuration could not generate the desired improvement, it was decided to investigate the possibility of effecting an improvement by means of this radical change in design concept.

Some encouragement for this approach is provided by published results for tail-less aircraft [4], where a change in design concept alone resulted in a 15% reduction in direct operating cost (DOC). However, the ground rules for the study described in Reference 4 differed somewhat from the present effort :

i) The Reference 4 study was conducted in the early 1960's, when fuel cost was a much smaller fraction of DOC than it is today.

SUBJECT
AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

ii) The DOC algorithm used in Reference 4 is different from the one used in recent Canadair studies (e.g., Reference 2).

iii) The Reference 4 study employed low bypass ratio turbofan powerplants, which were sized by the take-off field length requirement, whereas the thrust required from high bypass ratio turbofans like the CF-34 is determined by the design cruise speed at altitude.

iv) The stage length assumed in Reference 4 was some 300 nautical miles with a payload in excess of 100 passengers. For a consistent comparison with the baseline conventional aircraft, the all-wing concept must be sized for a 2200 nautical mile stage length with a 70-passenger payload.

Despite the conclusions of Reference 4, then, it is not possible to state *a priori* that the flying wing offers an improvement in the case of the present study. Nevertheless, Reference 4 does establish that benefits could be expected in certain instances.

The advent of supercritical wing technology has provided a further impetus to reconsider a flying wing configuration. For a given design lift coefficient and wing planform, the use of a supercritical airfoil section allows an increase in the wing thickness-chord ratio for the same drag divergence Mach number (M_d). Typical results are shown in Figure 2, taken from Reference 5.

SUBJECT AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

In practice, M_d corresponds closely to the design cruise Mach number (0.80 in this case). Therefore the use of supercritical airfoils in an all-wing configuration, by increasing the allowable thickness-chord ratio, could conceivably reduce the gross wing area needed to house all of the useful load within the wing. In the past, studies of all-wing configurations have shown them to be practical only for very large aircraft, precisely because the required thickness leads to excessively large wing areas. It was felt that application of supercritical airfoils to a 70-passenger flying wing could reduce the gross wing area to the point where the concept is competitive with the baseline conventional configuration. In order to estimate the size of such a flying wing, a geometric study of simple delta wing planforms was carried out and reported in Reference 6. For a series of aspect ratios, the thickness-chord ratio for $M_d = 0.80$ was estimated using Reference 7. The gross wing area could then be determined by specifying that, for the same passenger cabin floor area as the baseline conventional aircraft, there be at least 6 feet of depth within the wing. The results, shown in Figure 3, indicate reasonable overall dimensions for all aspect ratios considered, although the useful interior volume decreases sharply with increasing aspect ratio.

These results were encouraging; however, some reservations remained concerning the utility of supercritical wing technology in this application:

i) Because of the need to trim the relatively large nose-down pitching moments typical of supercritical airfoils, it might not be possible to achieve the full supercritical effect in a practical flying wing configuration.

SUBJECT
AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

ii) For relatively low aspect ratios, the use of supercritical airfoils might have little effect because the wing aerodynamics are more dependent on the wing plan form than on the airfoil section.

These and other concerns could only be resolved after further study.

As has been stated, the purpose of the study described in this report is to establish whether the all-wing configuration is significantly superior to a technologically-equivalent wing-body-tail arrangement for carrying 70 passengers plus luggage on a 2200 nautical mile mission. The purpose is not to establish the feasibility of the all-wing concept per se - this was established years ago by the pioneering work of John K. Northrop[8]. In the case of the XB-35 aircraft, Northrop achieved a minimum drag coefficient which was half that of contemporary bombers like the B-29. However, for an all-wing configuration which is statically stable in pitch, not all of the trailing edge devices can be deflected trailing edge down for landing, and this limits the maximum trimmed lift coefficient which can be achieved. The XB-35 attained a maximum trimmed lift coefficient of about 1.5, compared to 2.3 for conventional types. In order for the landing speed to remain the same, then, the plan area of the all-wing concept will be larger than the wing area of the conventional configuration in the ratio 2.3 : 1.5. Using subscripts aw and conv for the all-wing and conventional configuration, respectively,

SUBJECT AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

the parasite drags Dp will be in the ratio

$$\frac{(Dp)\ aw}{(Dp)\ conv} = \frac{(C_{d\ min})\ aw}{(Cd\ min)\ conv} \cdot \frac{S\ aw}{S\ conv}$$

$$= (0.50)\ \frac{2.3}{1.5}$$

$$= 0.77 \qquad (1)$$

Assuming a symmetric drag polar of the form

$$C_d = C_{d_o} + K.C_L{}^2 \qquad (C_{d_o} \approx C_{d_{min}})$$

where $K = \frac{1}{\pi\ Ae}$, then the aerodynamic efficiences are in the ratio

$$\frac{(L/D)aw}{(L/D)conv} = \sqrt{\frac{(Ae)\ aw}{(Ae)conv}} \cdot \sqrt{\frac{(Cdo)conv}{(Cdo)\ aw}}$$

$$\approx \sqrt{\frac{Aaw}{Aconv}} \cdot \sqrt{\frac{1}{.50}}$$

$$\approx 1.4 \cdot \sqrt{\frac{Aaw}{Aconv}}$$

$$\geq 1 \text{ for } Aaw \geq 0.5\ A\ conv \qquad (2)$$

SUBJECT AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

(An implicit assumption in this analysis is that the structural efficiency of the all-wing concept would be no worse than the conventional concept.)

Therefore, the potential exists for up to 40% improvement in aerodynamic efficiency, which for a given powerplant and cruise Mach number means a 40% increase in range for the same fuel fraction. As Aaw increases however, the results in Figure 3 show that the ratio Saw : Sconv may have to increase beyond 2.3 : 1.5 in order to accommodate the passenger cabin. On the other hand, as Aaw is decreased, the aerodynamic efficiency improvement relative to conventional aircraft disappears. There is clearly an optimum value for Aaw, which may or may not result in a flying wing configuration which is superior to a conventional configuration.

In the next section, the evolution of the all-wing configuration, including the choice of Aaw, is discussed for the present application.

SUBJECT AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

2.0 DESIGN EVOLUTION

2.1 Planform Trade-Off Study

The technology level for both the all-wing and the baseline conventional configuration is as follows:

propulsion : CF-34 (bypass ratio $\approx$ 6.4)

aerodynamics : supercritical wing technology (CL-600, CL-601 standard)

structures : composite materials in the primary structure, to an extent consistent with 1990's production.

In the case of composite materials, the procedure employed in previous studies was retained; that is, group weights are estimated assuming all-metal construction, and the weight saving factors derived in Reference 9 are applied to account for the use of composite materials. As was the case in Reference 2, these weight saving factors are conservative and indicative of a developing, rather than a mature, technology.

The above technology data, plus the requirement to carry 70 passengers and their luggage on a 2200 nautical mile mission, define the starting point for the all-wing design. Initially, a pure flying wing was assumed, with no appendages of any kind, although it was realized that this ideal would probably be departed from as the design progressed. The immediate need was to narrow down the range of feasible wing planforms, and a method was derived for this purpose.

SUBJECT
AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

The wing sizing method, briefly described in the Appendix, assumes that the 2200 NM stage length (with reserves) is equivalent to an all-out still air range of 3000 NM in a cruise-climb at Mach 0.80. Given the aspect ratio (A), quarter-chord sweep angle (Λ), taper ratio (λ) and lift coefficient (C_L), the method estimates lift-drag ratio (L/D), take-off thrust-weight ratio (T/W), wing loading (W/S), initial cruise altitude (ICA), fuel fraction ($\frac{W_f}{W}$) and take-off weight (W). Some typical results are presented in Figure 4 for A = 3, $\Lambda = 45°$ and $\lambda = 0.2$, for a range of C_L. The selection of C_L determines, after some iteration, the initial cruise altitude. For the range of lift coefficients shown in Figure 4, the fuel weight, given by $W_f = \frac{W_f}{W} W$, shows a minimum, in this case near $C_L = 0.22$.

For this C_L, results are : $(L/D) = 14.3$, $(T/W) = 0.54$, $(W/S) = 32$ psf, ICA = 44000 ft, $\frac{W_f}{W} = 0.311$ and W = 83800 lb.

The corresponding values for the conventional baseline configuration are $(L/D) = 17$, $(T/W) = .30$, $(W/S) = 88$ psf, ICA = 36000 ft, $\frac{W_f}{W} = .322$ and W = 82500 lb.

The minimum fuel weights estimated for each planform, including the above example, are plotted in Figure 5. As might be expected from the geometric study described previously[6], the best planforms tend to have low aspect ratios and high sweep angles. As shown, the example discussed above (A = 3 and $\Lambda = 45°$) is practically the optimum, but the fuel usage is only marginally better than the conventional baseline configuration. The results are therefore not very promising, in terms of achieving a significant improvement in energy efficiency via the flying wing configuration.

SUBJECT
AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

All of these results are for a taper ratio of 0.20. For any combination of A and Λ, the gross wing area needed to achieve the required external volume decreases continuously with λ. A value of $\lambda = 0.2$ was considered to be as small as practical without causing excessive tip loading, which would increase the tendency to early tip stall and an unstable break in the C_m - C_L curve (i.e., pitch-up).

In addition, it will not be possible to exploit supercritical wing technology to the fullest, for two reasons. First, the aerodynamics will be more dependent on the planform than on the airfoil section. Also, the values of C_L and W/S are considerably lower than for the conventional baseline aircraft, and supercritical wings operate best at high lift coefficients. This makes them more suitable for high aspect ratio wings, since the lift coefficient for best lift-drag ratio is given by

$$C_{L_{opt}} = \sqrt{\frac{C_{Do}}{K}} = \sqrt{\pi C_{D_o} Ae} \qquad (3)$$

so that the optimum lift coefficient increases with the square root of the aspect ratio. The maximum lift-drag ratio corresponding to C_{Lopt} is given by

$$\left(\frac{L}{D}\right)_{max} = \frac{1}{2\sqrt{C_{Do} K}} = \frac{1}{2} \cdot \sqrt{\frac{\pi Ae}{C_{Do}}} \qquad (4)$$

which also increases with $\sqrt{A}$. Put another way, a low C_{Do}, as for the all-wing configuration, leads to high cruise speeds and a low C_{Lopt}, as indicated by equation (3).

Despite these results, it was decided to continue with the study in the hope that a refined weight estimate would result in a significantly lower value for structural weight. The advanced design-type weight estimating algorithm used in the planform trade-off studies is a statistical method derived from a data base of existing aircraft weights. In the case of flying wing aircraft, the only aircraft in the data base is the YB-49, a forty-year-old design. Therefore, it was felt that a more detailed weights accounting could yield significant improvements.

2.2 Initial All-Wing Configuration

The results of the planform trade-off study lead to consideration of an all-wing configuration with A = 3, Λ = 45° and λ = 0.20. See Figure 6. Front and rear spars were located at 14% and 68%, respectively, with the passenger cabin between them. A higher level of realism was provided by including space for doors, aisles, toilets, coat racks and a galley. However, consideration was not given to a structural concept, or to balancing and trimming the aircraft. The wing was sized to achieve the needed passenger cabin floor area and volume.

From purely geometric considerations, then, Figure 6 shows that a wing area of over 4700 square feet results - an 81% increase over the wing area one would expect, based on the trade-off results in Figure 4. Clearly, such a large increase would more than negate any gains that might be expected from an improved structural weight estimate. It is concluded that a pure all-wing configuration is not viable in this case. As a result, subsequent effort was concerned with identifying a viable concept lying somewhere between the

conventional layout and the pure all-wing. This led naturally to consideration of a blended wing-body configuration.

2.3 Blended Wing-Body Configuration

The consideration of a blended wing-body configuration arises from the need to reduce the wing area without entirely eliminating the assumed advantages of a pure all-wing configuration. At this point, the need to consider the structural concept becomes apparent, as it strongly influences the shape of the pressure vessel and the relative dimensions of wing and body. A viable structural concept is also required for an improved weight estimate. After many iterations, the arrangement shown in Figure 7 was adopted.

The pressure vessel consists of two side-by-side cylinders with their axes oriented longitudinally. A twin-aisle, 10 abreast seating arrangement is chosen with two cargo bays beneath the floor. Cargo volume slightly exceeds that available in the conventional baseline configuration. There are no structural supports internal to the pressure vessel. The concept lends itself to multi-spar wing construction so that the wing loads may be passed through a number of frames. The wing is oriented vertically on the pressure vessel so that the upper surface skin panels are continuous and the cabin floor carries most of the tension load passed from the lower spar caps.

SUBJECT AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

A plan view of the centre section of the aircraft is shown in Figure 8, along with an inboard profile. Two passenger doors, 36" x 72" , are provided at the front of the cabin on each side, along with two Type III exits. Because of the twin-aisle arrangement, these exits should be sufficient to meet the emergency evacuation requirements of FAR Part 25. If not, emergency exits leading to the upper surface of the aircraft could be installed at the rear of the passenger cabin.

There are two windows next to each door, plus skylights in rows above each aisle, in order to avoid a feeling of claustrophobia. However, the fact that the majority of passengers are relatively far removed from windows may not be an issue, since a significant proportion of passengers riding today's wide-body aircraft face a similar situation.

The rear pressure bulkhead is flat, to conserve space. The engines are most conveniently located aft, although the intake ducts are then required to pass through the pressure vessel. The engines must be grouped close to the aircraft centreline in order to minimize engine-out yawing moments.

The general arrangement is shown in Figure 9. The gross wing area is 2654 square feet, a reduction of some 44% compared to the pure all-wing. The change to a blended wing-body configuration therefore results in a significantly reduced wing area which is comparable to the 2618'[2] inferred from Figure 4. However, the wing aspect ratio is reduced to 2.86 from 3 and the quarter-chord sweep angle is increased to 50° from 45°, in order to achieve an

acceptable balance with minimum wing area. The weight and balance estimate is summarized in Figure 10. A good balance is achieved, with only about 2% c.g. travel between OWE and Ramp Weight. However the Ramp Weight, at 83040 lb, is only 1% less than the estimated value of 83800 lb, resulting from the planform trade-off study discussed in Section 2.1. The includes the effect of composite materials, which were extensively used in the wing outboard of the trailing edge kink. Consequently it appears that, even with a viable structural concept and an improved weight estimation, there is little weight saving compared to the conventional baseline concept.

The above weight estimate assumes a fuel load of 24,000 lb and 3 CF-34 turbofans. From Figure 4, it would appear that the concept is somewhat underpowered. Whereas the highest T/W for this concept is about 3 x 10,500/83,040 = .38, Figure 4 shows T/W = .54 for the selected configuration. A mission analysis is also needed to determine if 24,000 lb of fuel is sufficient for the design mission. In addition, some consideration of stability and control is required. These issues are discussed in the next section.

SUBJECT
AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

2.4 Performance, Stability and Control

2.4.1 Performance

As for the planform trade-off study, it is assumed that the design mission is equivalent to an all-out still air range of 3000 nm in a cruise-climb at Mach 0.80. The concept shown in Figure 9 has the following characteristics:

S = reference wing area = 2532 ft²
W = all-up weight = 83040 lb
A = wing aspect ratio = 2.86
Λ = quarter-chord sweep angle = 50°
S_{wet} = total wetted area = 5755 ft²

The drag equation is taken to be

$$C_D = C_{Do} + \frac{C_L^2}{\pi Ae} + C_{D_w} \quad \text{(based on S)} \qquad (5)$$

where $C_{Do} = 0.0090$
$e = 0.90$
$C_{Dw} = 0.0015$

The zero-lift drag coefficient, C_{Do}, is estimated using Reference 10. The value for Oswald efficiency factor, is chosen somewhat larger than the value expected for conventional turbofan layouts (0.80 - 0.85) to account for the improved spanwise lift distribution expected with the blended wing-body. C_{Dw}, the wave drag, is estimated using Reference 7.

SUBJECT AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

With this drag equation and the CF-34 engine characteristics, the fuel fraction is given by the Breguet range equation for the cruise-climb; i.e.,

$$\text{S} = 1 - e^{-R/B} \qquad (6a)$$

where $$B = \frac{V}{SFC}\,\frac{L}{D} \qquad (6b)$$

If the wave drag is neglected, Figure 11 shows how $\frac{L}{D}$ varies with altitude at Mach 0.80 for both the blended wing-body and the conventional baseline configuration. At typical ICA's for a 3000 nm mission, the conventional baseline configuration exhibits a superior $\frac{L}{D}$, and the difference increases with increasing altitude. Since, for a given altitude, both aircraft fly at the same V, with the same SFC because they use the same engines, then the fuel fraction S will always be smaller for the conventional baseline configuration. This is confirmed in Figure 12. Note that in Figure 12, the assumed weight for the blended wing-body configuration is W = 83040 lb, assuming a fuel weight of W_S = 24000 lb as per the previous section. It is clear from the figure that both of these weights are too small. On the one hand, if three engines are to be used, the minimum S is 0.337 at an ICA of 34000 ft, compared to the assumed S of 24000/83040 = 0.289. On the other hand, a lower S would require a higher ICA, and at least four engines would be required. Moreover, locating a fourth engine would pose a layout problem. For the design mission, then, the weight of the blended wing-body configuration would significantly exceed 83040 lb, which is already more than the 82500 lb of the conventional baseline configuration. The blended-wing body configuration is thus not competitive in this application, despite a greatly reduced C_{Do} (.0090 vs .0222), a higher e (0.90 vs 0.85), and no consideration of C_{Dw}.

SUBJECT
AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

This conclusion is reinforced by a comparison on the basis of Direct Operating Cost. By means of a few simplifying assumptions, the following approximate expression for the DOC can be derived for the 3000 nm cruise-climb:

$$\frac{DOC}{W}\left(\frac{1982\ US¢}{ASNM\text{-}lb}\right) = 1.8906\times10^{-5} + \frac{1.45}{W} + (7.2914\times10^{-5}\ FP - 1.5321\times10^{-6})\ S + 2.5879\times10^{-5}\ \frac{T}{W} \qquad (7)$$

For the baseline conventional configuration, this expression gives a value for DOC which is within a few per cent of the value obtained using the full NASA-American Airlines method, assuming :

- an airplane cost of $150 US per lb W;
- an engine cost of $96 US per lb T;
- an engine weight-to-thrust ratio of 0.19 lb per lb T.

Assuming that the engines would be sized for the cruise thrust requirement, then $\frac{T}{W} = \frac{I}{g}\ \frac{Tcr}{W} = \frac{I}{g\ (\frac{L}{D})}$

so that one can derive the following DOC parameter

$$\frac{DOC - 1.45}{W\times10^{-5}} = 1.8906 + (7.2914.FP - 0.1532).\ S + \frac{2.588}{g\ (\frac{L}{D})} \qquad (8)$$

This parameter is plotted in Figure 13 as a function of FP and ICA, given $\frac{L}{D}$ and S from Figures 11 and 12 and g from CF-34 engine data. Even on a per pound basis, the DOC parameter for the blended wing-body configuration is some 10% higher. The absolute DOC difference can be expected to be larger because W is larger for the blended wing-body than for the conventional baseline configuration.

2.4.2 Stability and Control

No detailed analysis of the stability and control of the blended wing-body configuration was undertaken in light of the results of the performance analysis. However, some general aspects of all-wing or blended wing-body design were considered:

i) In order to inhibit pitch-up at the stall, a tip slot would likely be required to increase the stalling angle of the tip wing section. As in the case of the Northrop XB-35 aircraft, the slot would lie on roughly the 15% chord line and extend over the outer 20% or so of the span. The slot would be normally closed, as in cruising flight, and be opened automatically when the suction on the upper wing surface reached a certain value.

ii) Spoilers would be used in lieu of ailerons for roll control. The spoilers would provide a yawing moment to assist the turn, rather than the adverse yaw typical of conventional ailerons. Moreover, the use of spoilers would permit the outboard trailing-edge devices to be used exclusively for trim, without the need to provide a margin for manoeuvre control. The spoilers would also be used as lift dumpers on landing.

SUBJECT
AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

iii) The concept in Figure 9 is equipped with winglets. Even though the cruise lift coefficient is low, the low aspect ratio implies that winglets can provide a meaningful reduction in induced drag (rough calculations show that a 10% increase in e could be expected). In addition, the winglets will contribute significantly to the directional static stability of the vehicle, and move the aircraft aerodynamic centre further aft.

iv) In order to counteract engine-out yawing moments and actively augment directional static stability, Northrop drag rudders would be employed. These devices are essentially split flaps on the outboard trailing edge. When opened, they provide a yawing moment due to the increased drag; when closed, the device acts as an elevator. No calculation of the rigid body dynamics was undertaken, so it cannot be said with certainty that the directional stability would be adequate without some sort of vertical tail. Of course, any vertical tail would make the concept all the more unattractive.

v) The vehicle aerodynamic centre is estimated to be at about 34% mean aerodynamic chord. From Figure 10, the resulting static margin at full payload is some 5%. The appropriate static margin is a matter for conjecture at this point. Too much static margin will make the vehicle extremely sensitive to gusts in view of its low wing loading. As the static margin is reduced, the vehicle becomes more manoeuvrable and the maximum trimmed lift coefficient increases; however, too little static margin makes the

SUBJECT
AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

aircraft uncontrollable without stability augmentation. A 5% static margin is felt to be a reasonable value for this vehicle, if adequate control without a flight-crucial stability augmentation system is a requirement. If not, the vehicle is a natural candidate for negative static margin; in this case, all trailing edge devices can be deflected trailing edge down in the high lift configuration, so that maximum trimmed lift coefficients comparable to conventional aircraft may be achieved. Moreover, the high values of wing twist required to achieve a positive value of zero lift pitching moment can then be avoided, and the wing twist can be tailored to minimize the induced drag.

SUBJECT
AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

3.0 DISCUSSION

In this section, the results in Reference 4 are reviewed in an attempt to resolve the results of that effort with the conclusions of the present study. In Reference 4, it was concluded that, compared to a contemporary conventional configuration, a technologically-equivalent tail-less concept offered a 15% improvement in DOC, even for an aspect ratio of 1.5 or less.

Some of the differences between Reference 4 and the present study are discussed in Section 1.0. One of these differences is in the DOC algorithm. A simplified version of the Reference 4 algorithm is as follows, for cruise-sized engines and an all-out cruise-climb mission above or near the tropopause :

$$\frac{DOC}{Wx10^{-5}}\left(\frac{1965\ \text{pence}}{\text{ASNM - 1b}}\right) = (1.5633 + \frac{125}{R}) + \frac{2500}{R}\$ + \frac{0.1779}{g\left(\frac{L}{D}\right)} \qquad (9)$$

Compared to the simplified NASA-AA algorithm, Equation (8), there are some significant differences. First of all, Equation (9) is an explicit function of R, whereas in Equation (8), R = 3000 nm is implicit. For R = 3000 nm, Equation (9) becomes :

$$\frac{DOC}{Wx10^{-5}} = 1.605 + 0.833\$ + \frac{0.1779}{g\left(\frac{L}{D}\right)} \qquad (10)$$

A comparison of the terms in this equation with Eqn (8) reveals that the achievement of a high $\frac{L}{D}$ has much less effect on lowering DOC in the case of Eqn (10), because the numerical coefficient of this term is over one order of magnitude smaller than the corresponding

SUBJECT
AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

term in Eqn (8). Thus the differences in $\frac{L}{D}$ shown in Figure 11 would result in smaller DOC differences when Eqn (10) is used in place of Eqn (8).

Another difference between these equations is in the form of the fuel fraction coefficient. Although the coefficient of S in Eqn (10) is about one order of magnitude smaller than the corresponding coefficient in Eqn (8), most of this difference is probably attributable to the huge increase in fuel price over the intervening period. While FP is explicitly represented in Eqn (8), it is unfortunate that DOC is only an implicit function of FP in Eqn (10). Otherwise, it would be possible to quantitatively examine the effect which fuel price increases have undoubtedly had on the conclusions reached in this study, compared to Reference 4.

Another difference between the two studies is in the type of powerplant which was used. Reference 4 employed turbofan engines of the Rolls-Royce Spey type (bypass ratio $\approx$ 1.0, SFC $\approx$ 0.61 at take-off, sea level), which was state-of-the-art at that time. The General Electric CF-34 (bypass ratio $\approx$ 6.4, SFC $\approx$ .36 at take-off, sea level) is a much more efficient powerplant. For the ICA's typical of the 3000 nm cruise-climb, the CF-34 is sized for cruise while the Spey type is sized for take-off, so that the SFC difference in cruise is even larger than indicated above for take-off. Nevertheless, it is felt that this factor is not a significant contributor to the differing conclusions reached by the two studies. This is because, within each study, aircraft

SUBJECT
AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

concepts are compared which are technologically equivalent, even to the same engine. It is layout aspects which primarily determine the relative merits of the conventional and unconventional configurations.

A major difference between the two studies is with respect to the design mission, and this can be examined quantitatively using various forms of Equation (9). This difference has two aspects : the overall mission range, and the mission profile.

The effect of range is considered in Figure 14. Equation (9) has been used, assuming an all-out cruise climb for the given R, and $\frac{S}{}$ is computed as a function of R using Equation (6). (Rather than use absolute values of DOC/W, it was decided to present the results in terms of relative DOC/W in order to avoid unnecessary and indeed irrelevant comparison with Figure 13, in which case 1965 British pence would have to be converted to 1982 US cents.) The results show that the effect of R alone on the relative merits of the two configurations is slight. Clearly the reason for the different study results lies elsewhere, and attention is turned to consideration of the mission profile.

The design mission of Reference 4 has a stage length of 250 statute miles (217 nm). The cruise flight condition is Mach 0.80 at an altitude of 20,000 ft. Ideally, one would like to compare the blended wing-body concept and the conventional baseline configuration for this mission, and compare the resulting DOC's using the Reference 4 algorithm. In this case, an expanded version

SUBJECT
AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

of Equation (9) is required, namely, for R = 250 s.m.,

$$\frac{DOC}{Wx10^{-5}} = 0.50 + 10.0\,\$ + \left[2.869 + 0.3265\left(\frac{T}{W}\right)\right] . BT \qquad (11)$$

Note that DOC is expressed as a function of $\frac{T}{W}$ again, as in Equation (7), since for this mission it cannot be assumed that the engines are sized for cruise. Also, the block time BT has been introduced.

The reasoning for the introduction of BT is as follows. For this mission, the block time will be about 0.7 hours, compared to 6.5 hr for the 3000 nm cruise-climb. Therefore any differences between the block times for the two concepts can have a fairly large impact on DOC for the shorter mission. Related to this aspect is the fact that the blended wing-body concept, like the tail-less concept in Reference 4, is characterized by a higher $\frac{T}{W}$ and lower $\frac{W}{S}$ than the conventional baseline configuration. One of the consequences of this is a higher climb speed and rate of climb for the unconventional concepts. As a result, the cruise segment is a larger proportion of the overall mission (which tends to reduce \$) and the block time is reduced, compared to conventional aircraft. Both factors tend to reduce DOC.

The results of this comparison are presented in Table I Although, as shown in Figure 12, the blended wing-body configuration is too small for the 3000 nm cruise-climb, in this case the concept in Figure 9 has enough thrust and fuel capacity for the 250 sm mission. For this mission, both the conventional baseline configuration and the blended wing-body configuration are assumed

SUBJECT
AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

to take-off at MZFW plus enough fuel for the mission, plus about 10% fuel reserves. In other words, the aircraft have not been resized for the shorter mission.

The results show that the blended wing-body configuration does have a shorter block time and a higher climb speed than the conventional baseline configuration. However, the differences are not enough to bring the DOC for the blended wing-body configuration low enough to equate to the DOC of the conventional baseline configuration.

Table I also shows results for the tail-less concept of Reference 4. This vehicle has a passenger capacity of 154 and an aspect ratio of 1.54. The block time is 6% shorter than the conventional baseline configuration, and the best climb speed is 121 KEAS more. These factors contribute to the DOC being 77% of that for the conventional baseline configuration for the reasons discussed above. Most of this improvement, though, is probably due in this case to the increase in passenger capacity. With more passengers, it is much easier to get the aspect ratio down and the wing loading and C_L up without penalty. The conclusion is that for very short missions, an unconventional configuration could conceivably be superior to a conventional configuration for larger passenger capacities than considered here. For a longer range mission, the configuration of Reference 4 is not efficient enough at high-altitude cruise to be competitive with the conventional baseline configuration.

SUBJECT AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

4.0 CONCLUDING REMARKS

The results of this study indicate that for a small commercial transport with a capacity of 70 passengers, a conventional wing-body-tail configuration is more efficient, in terms of fuel used and direct operating costs, than an all-wing configuration. This depends, to some extent, upon the length of the design mission since, for very short stage lengths, it is possible for an unconventional configuration to show a DOC improvement over a conventional configuration through a decrease in block time, if the thrust-to-weight ratio and best climb speed are high enough. However, in today's economic environment, a commercial transport aircraft must have the operational flexibility to fly efficiently over the longer stage lengths as well. Indeed, the average stage length of American trunk carriers is steadily increasing as a result of deregulation. An aircraft optimised for very short stage lengths would not be well received by the marketplace.

The difficult layout problems associated with the all-wing concept in this study led to the selection of a blended wing-body configuration. A larger passenger capacity would have been easier to deal with. With more passengers, it is conceivable that the passenger density, in terms of passengers per square foot of wing area, could be significantly increased by extending the passenger cabin along the span of the wing. The result, in a large enough aircraft, would be higher values of wing loading, lift coefficient, lift-drag ratio and aspect ratio than were possible in this study. However, the aircraft may have to become extremely large to be competitive with a conventional layout.

SUBJECT AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

5.0 REFERENCES

1. Larson, George C. : " Lippisch and the Delta Wing" , Business and Commercial Aviation, May 1982

2. Whyte, P.H. : " Energy Efficient Aircraft Study, Phase III, Technical Report" , Canadair Report RAX-000-159, September 1982

3. Whyte, P.H. : " Energy Efficient Aircraft Study, Phase I, Volume I - Technical Summary" Canadair Report RAX-000-152, April 1980

4. Lee, G.H. : " Possibilities of Cost Reduction with All-Wing Aircraft" , Journal of the R Ae S, Vol. 69, November 1965

5. Lynch, F.T. : " Commercial Transports - Aerodynamic Design for Cruise Performance Efficiency" , Transonic Aerodynamics, Volume 81, Progress in Astronautics and Aeronautics, AIAA, 1982

6. Gagnon, B. : " Estimate of Overall Flying Wing Dimensions" , ADT/82-58, 9 June 1982

7. Whyte, P.H. : " A Preliminary Design Method for Predicting the Drag Rise Mach Number of Conventional and Supercritical Wings" , AD/80-06, 12 May 1980

8. Northrop, John K. : " The Development of All-Wing Aircraft" , 35th Wilbur Wright Memorial Lecture, Royal Aeronautical Society, 29 May 1947

9. Edwards, R.G. : " Energy Efficient Aircraft Study, Phase I, Volume III - Composite Materials" , Canadair Report RAZ-000-477, January 1980

10. Roskam, J. : " Methods for Estimating Drag Polars of Subsonic Airplanes", published by the author, 1971.

SUBJECT
AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

TABLE I - RESULTS OF 250 S.M. MISSION ANALYSES

	CONVENTIONAL BASELINE CONFIGURATION	BLENDED WING-BODY	TAIL-LESS CONCEPT (Ref. 4)
Take-off wt for 250 sm mission (lb)	60,000	64,000	103,000
N° of passengers	70	70	154
Best climb speed (KEAS)	208	225	329
~~Ws~~ (lb)	3,714	4,257	5,050
A	12	2.86	1.54
T/W	.303	.379	.505
W/S (psf)	88.0	32.8	43.8
~~S~~	.0619	.0665	.0490
BT (M)	.707	.692	.667
Relative DOC	1.000	1.072	.766

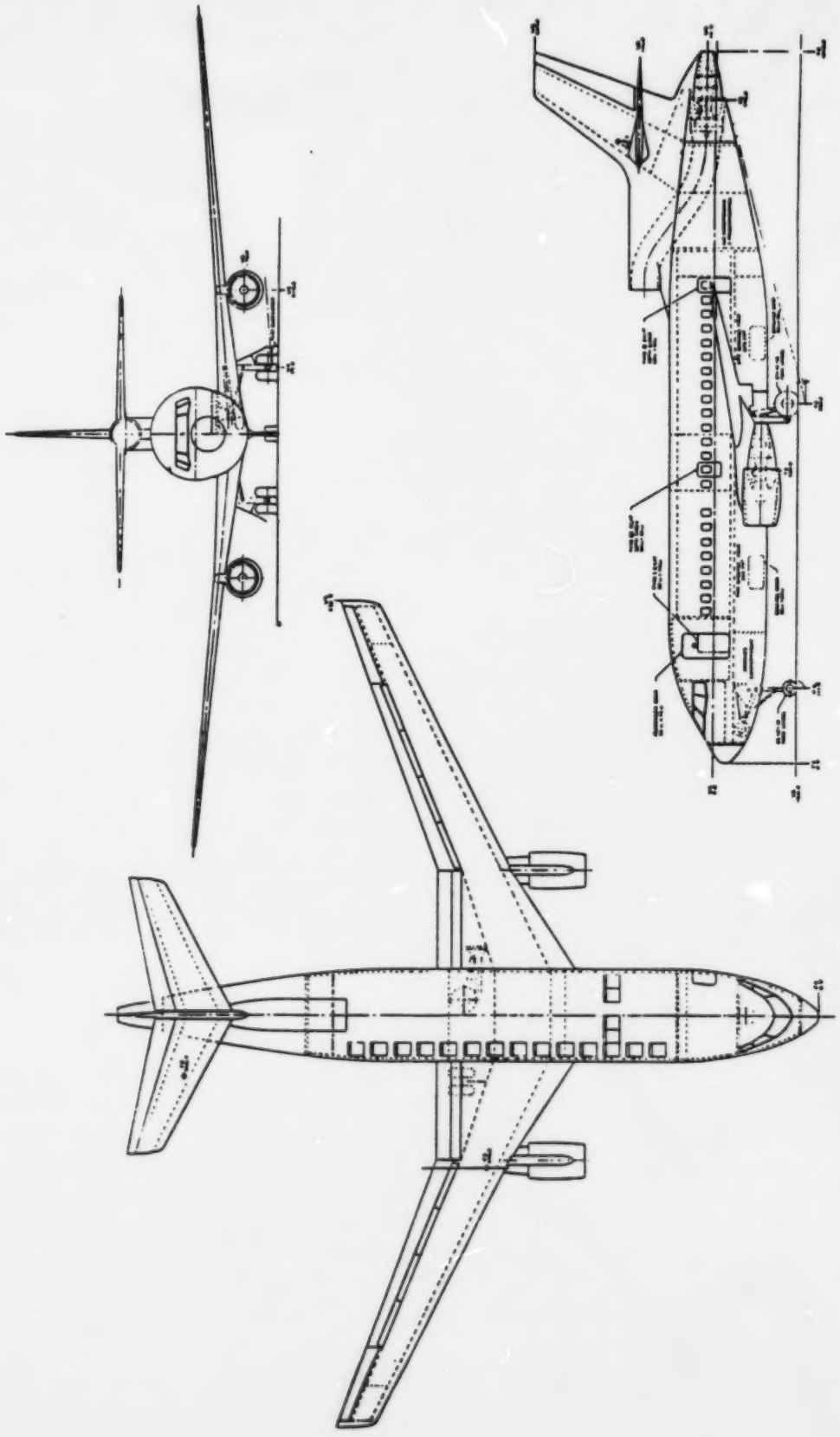


FIGURE 1
BASELINE CONVENTIONAL CONFIGURATION (REFERENCE 1)

FIGURE 2
THE EFFECT OF SUPERCRITICAL WING TECHNOLOGY

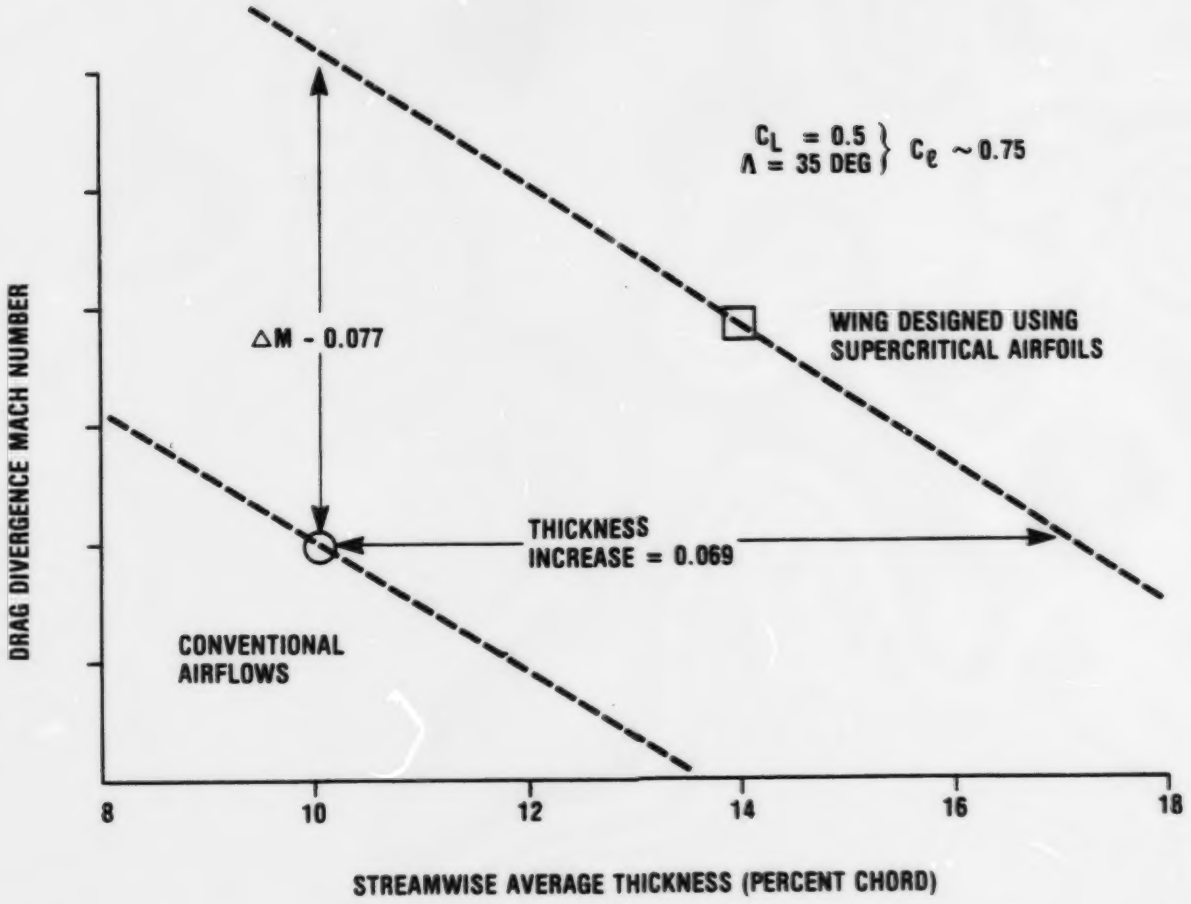


FIGURE 3
ESTIMATED OVERALL FLYING WING DIMENSIONS

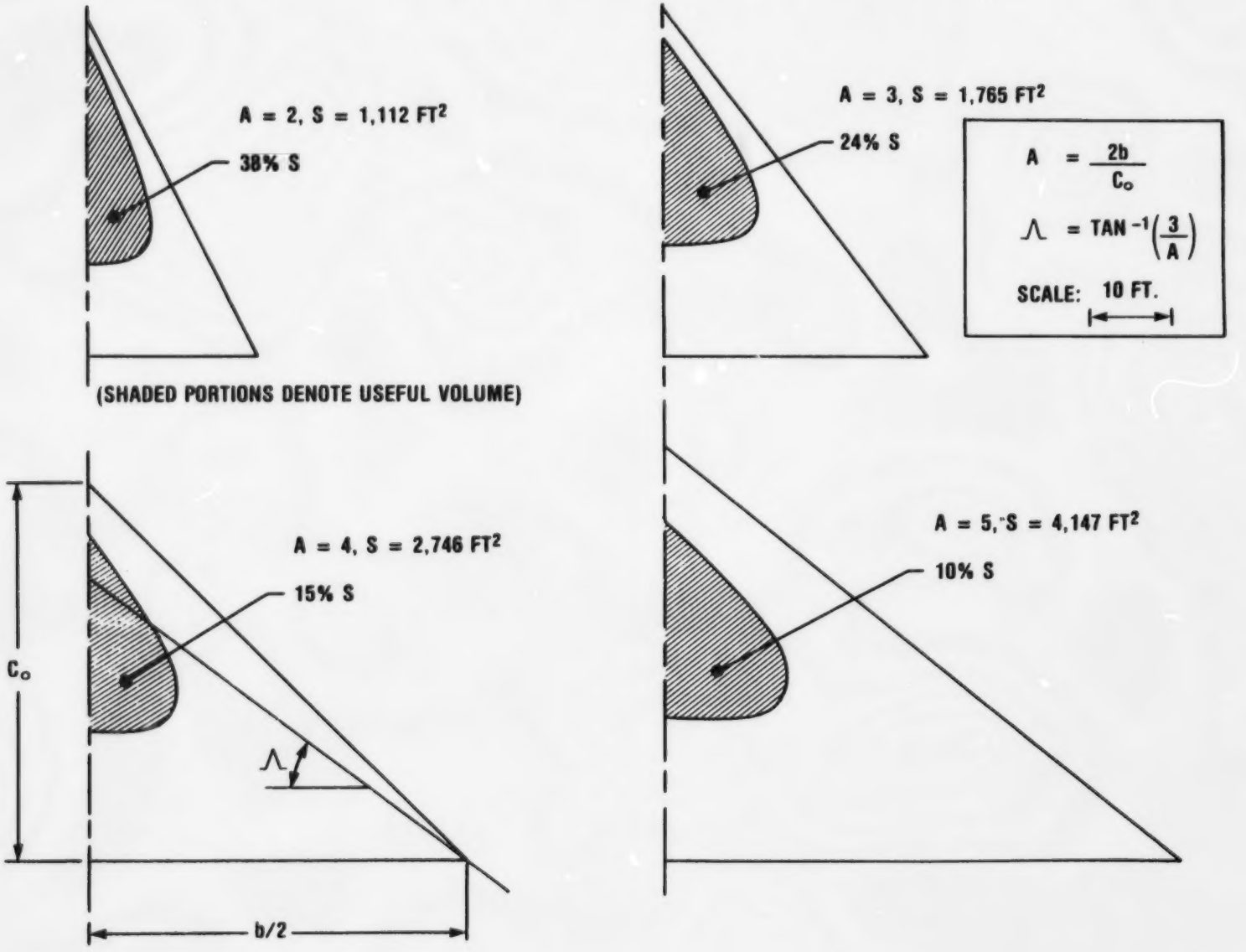


FIGURE 4

TYPICAL RESULTS OF PLANFORM TRADE-OFF STUDY

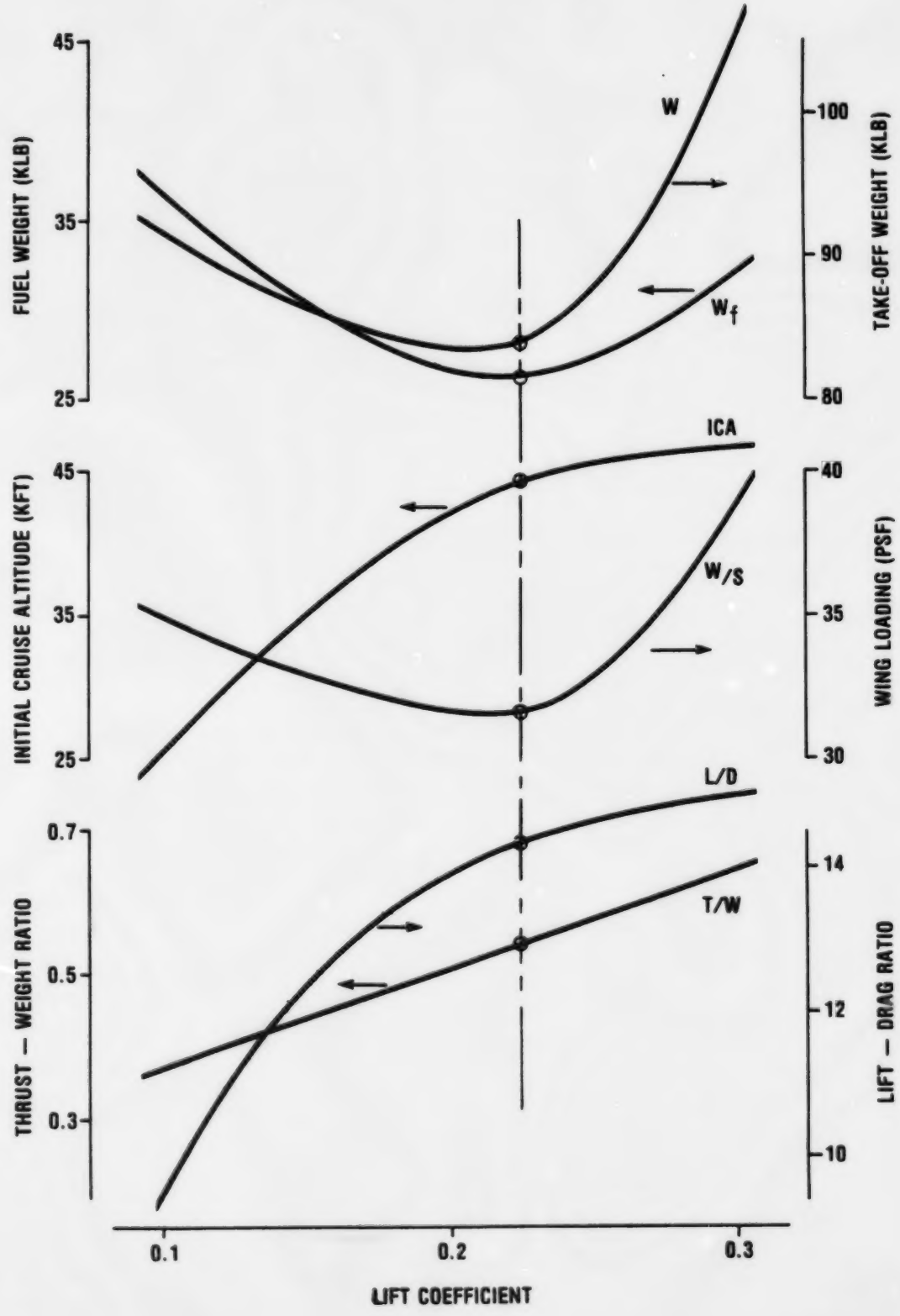
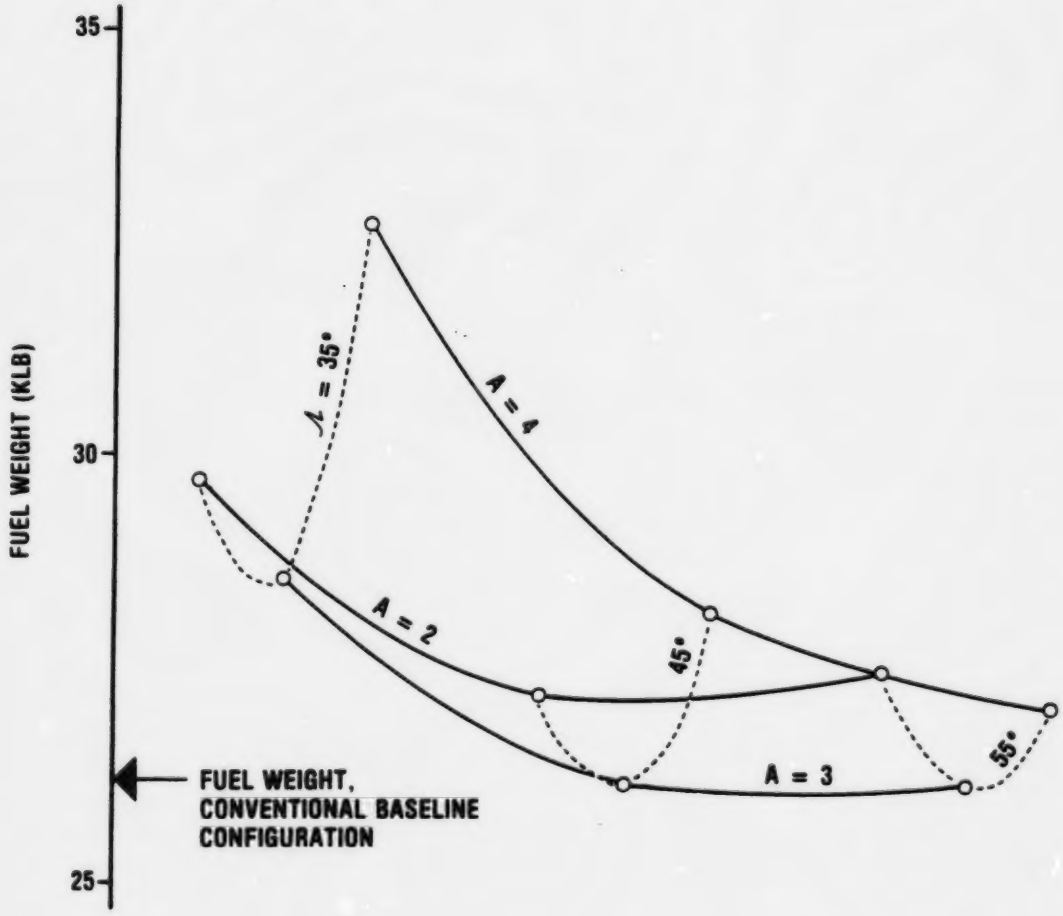
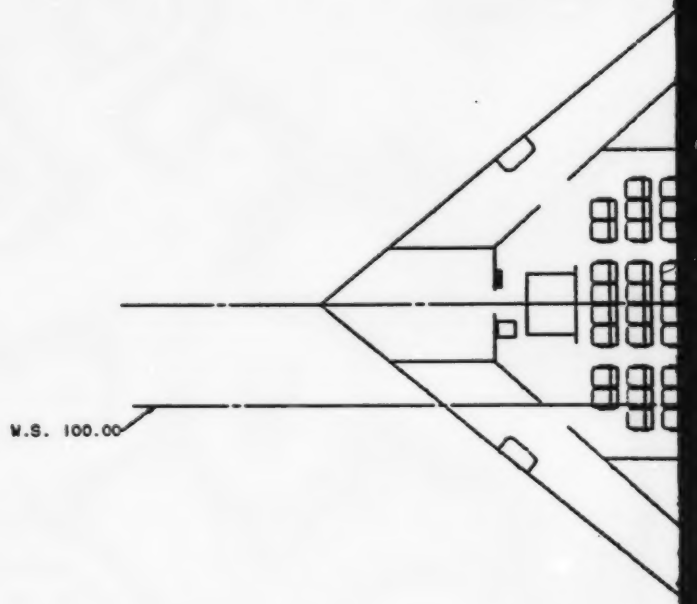
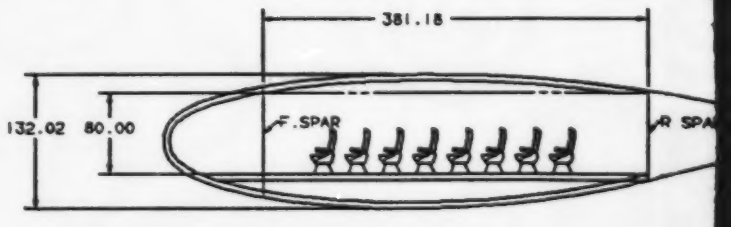


FIGURE 5
EFFECT OF WING PLANFORM ON FUEL USAGE



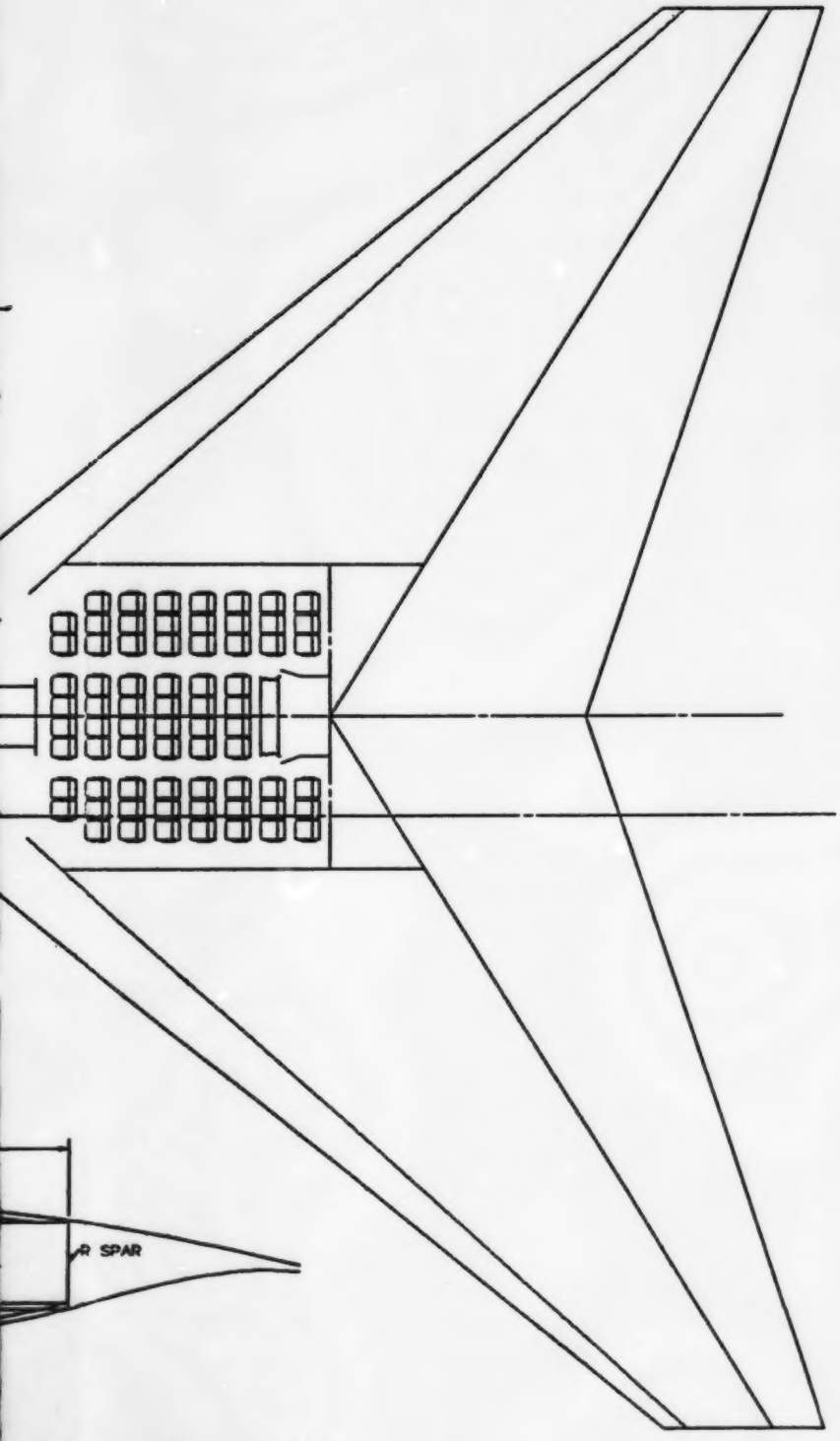
AREA	- 4737 SQ. FT.
A.R.	- 3
SPAN	- 119.2 FT.
ROOT CHORD	- 66.2 FT.
TIP CHORD	- 13.3 FT.
T/C	- .187
TAPER RATIO	_ .2
CAPACITY	- 70 PASS.
S.CABIN/S.WING	- .19





SECTION AT W/S 100.00
LOOKING INBOARD

FIGURE 6 - INITIAL ALL-WING CONFIGURATION



GURATION

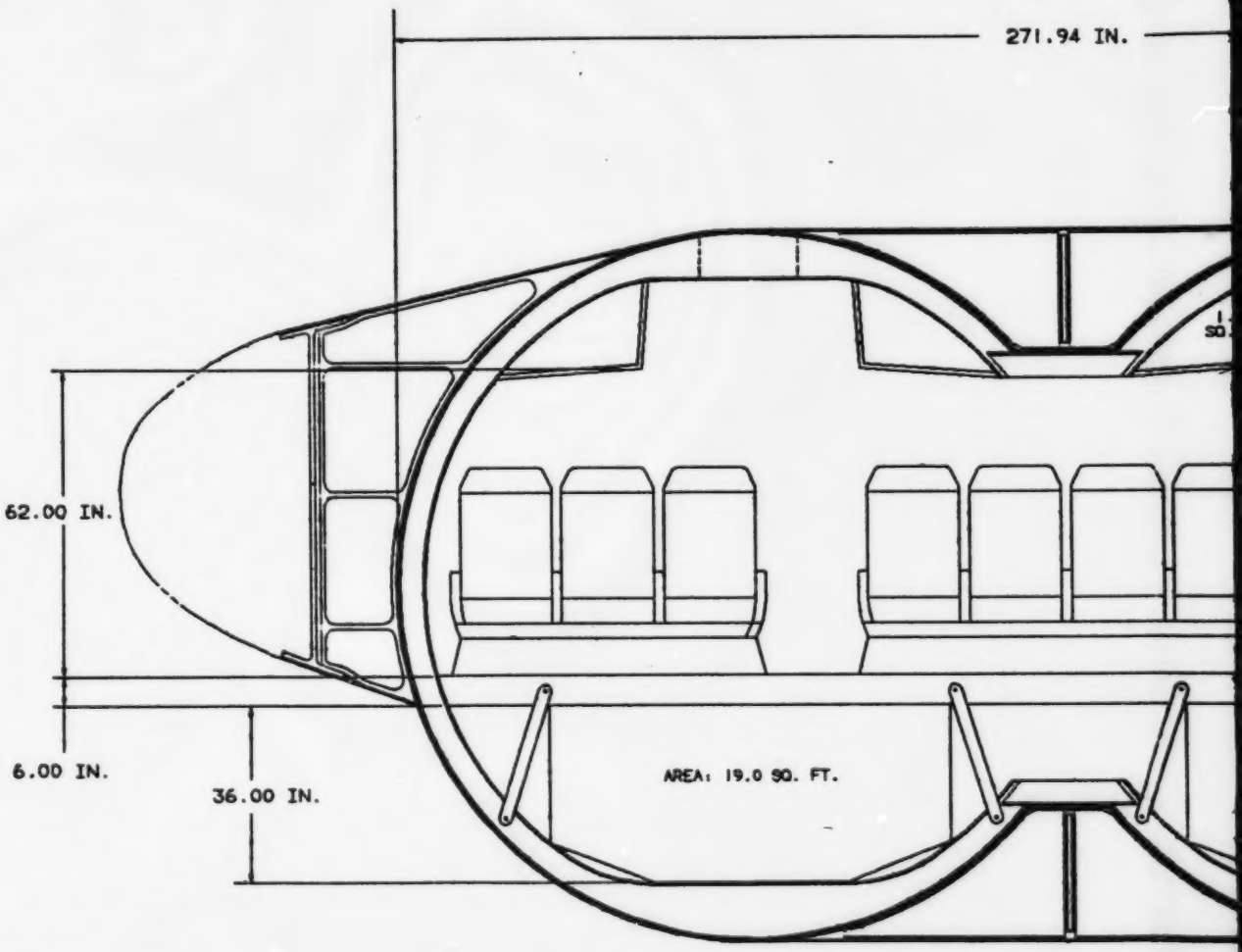
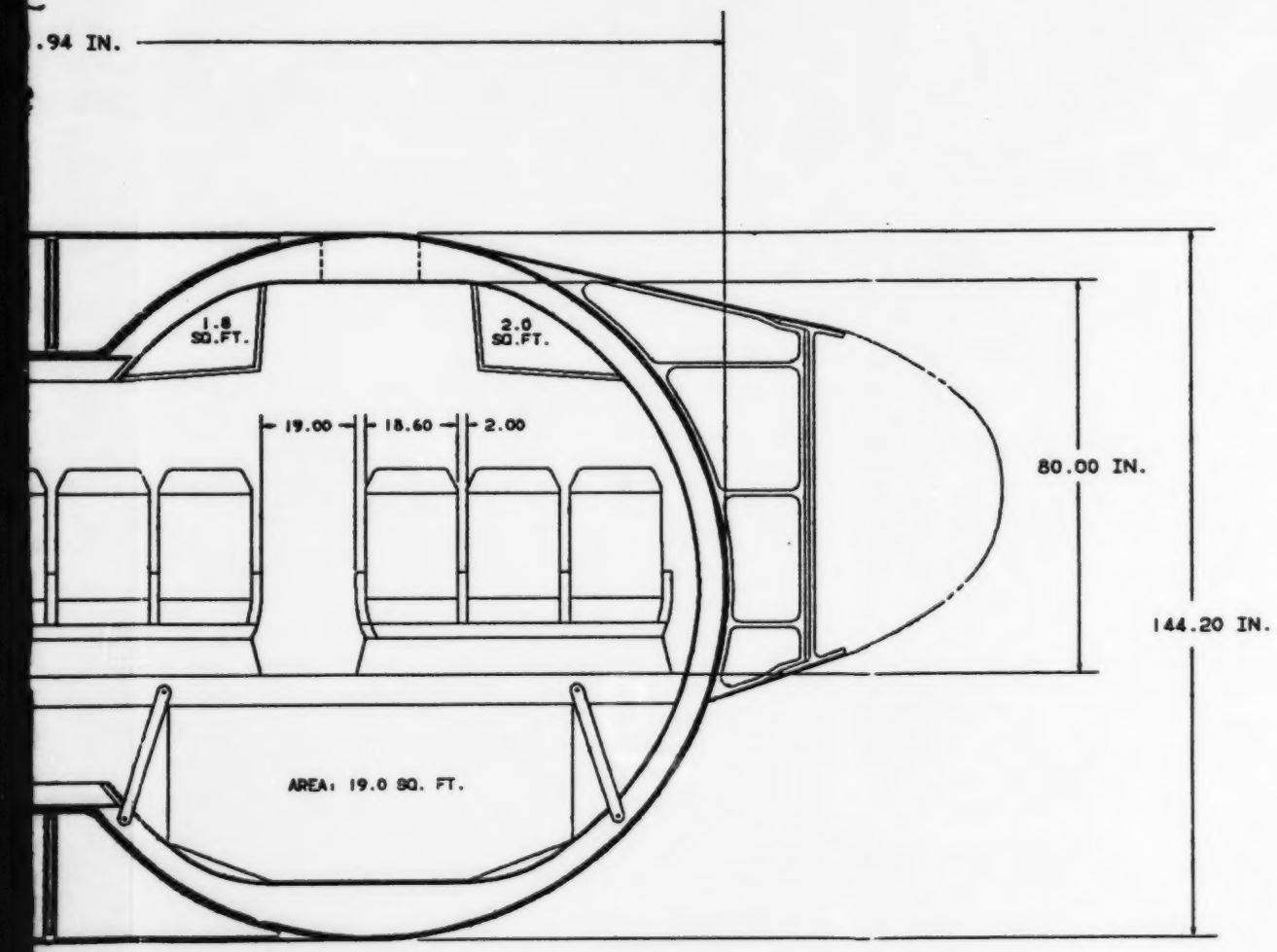


FIGURE 7- PASSENGER CABIN CROSS



ER CABIN CROSS-SECTION

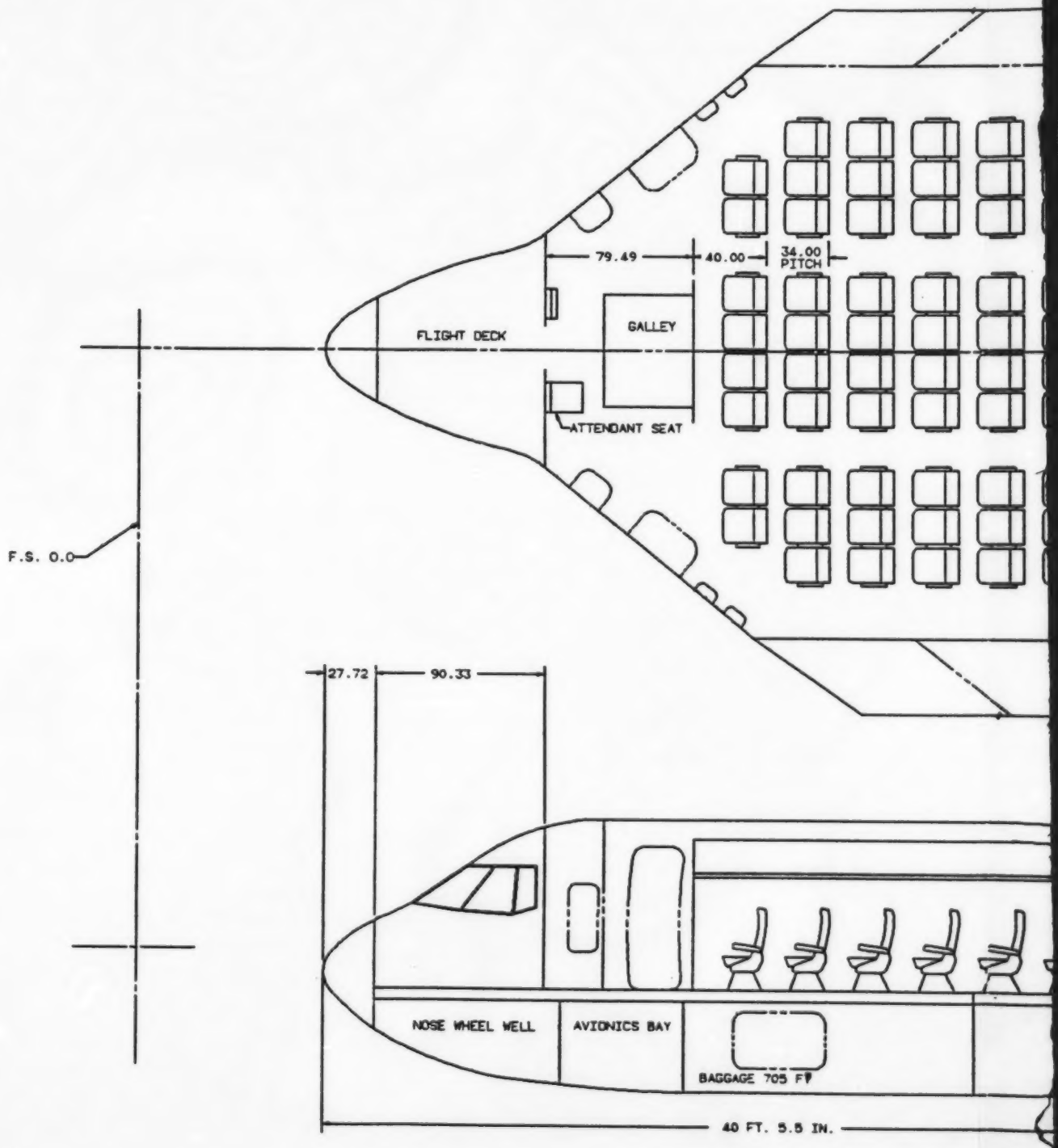
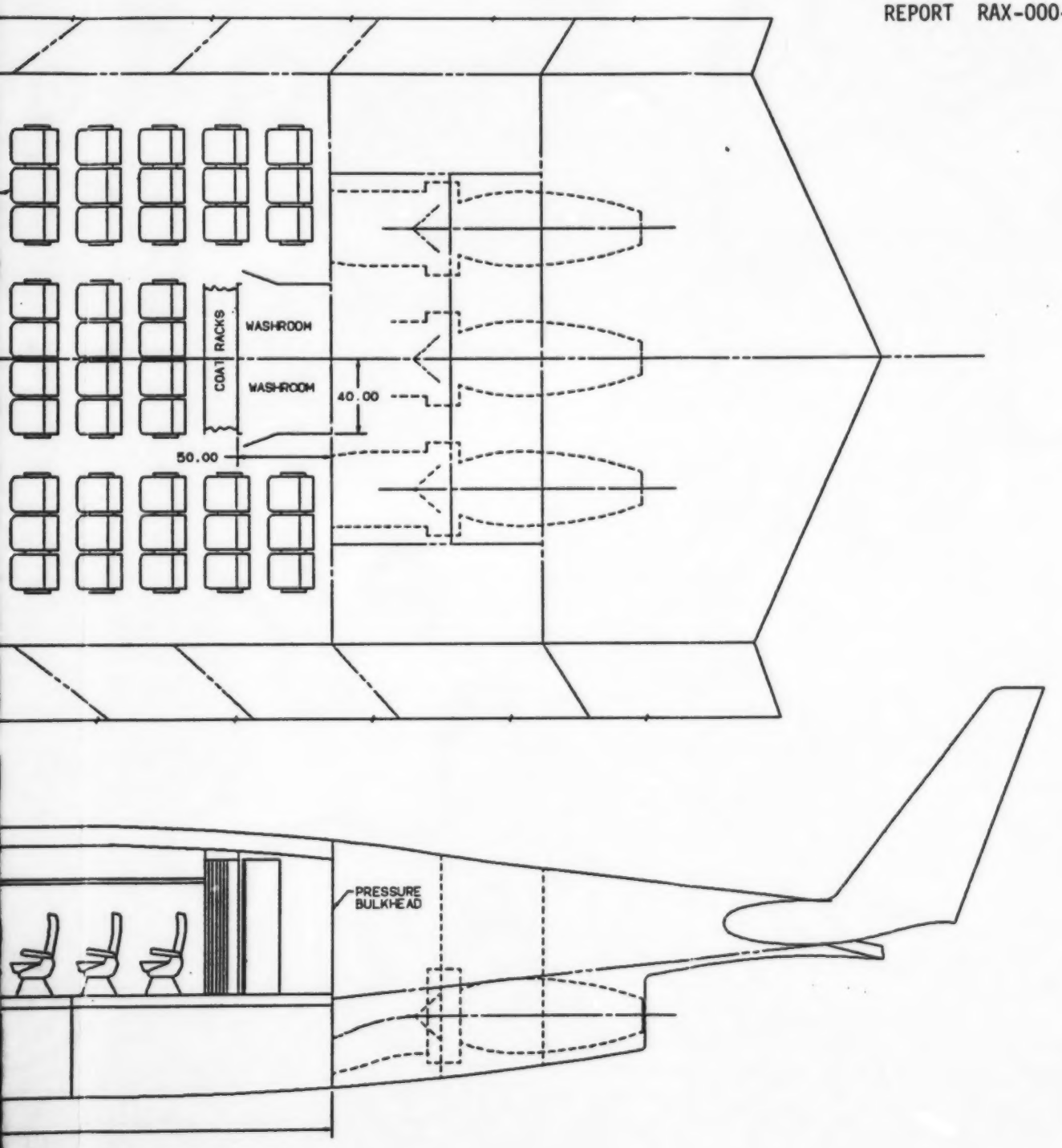


FIGURE 8- CENTRE SECTION PLAN VIEW AND INBOARD PROFI

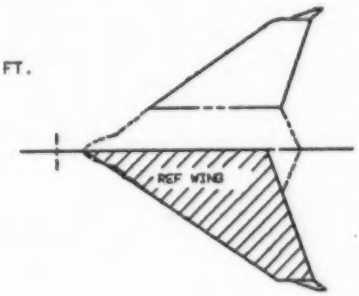


INBOARD PROFILE

GROSS PLANFORM AREA- 2654.53 SQ. FT.

REF. WING

AREA	-	2532.32 SQ. FT.
SPAN	-	85.12 FT.
ROOT CHORD (℄)	-	54.22 FT.
TIP CHORD	-	10.68 FT.
SWEEP (1/4 CHORD)	-	50°
ASPECT RATIO	-	2.86
TAPER RATIO	-	0.20
DIHEDRAL	-	0°
T/C (ROOT)	-	.187
T/C (TIP)	-	.187
M.A.C.	-	37.32 FT.



WEIGHTS

M.W.E.	-	42,400 LBS.
O.W.E.	-	45,040 LBS.
Z.F.W.	-	59,040 LBS.
RAMP W.T.	-	83,040 LBS.

CAPACITY

NO. OF PASS.	-	70

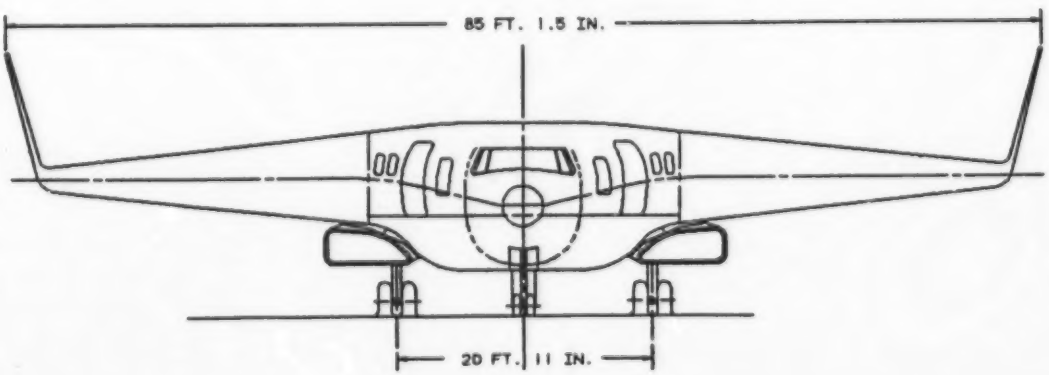
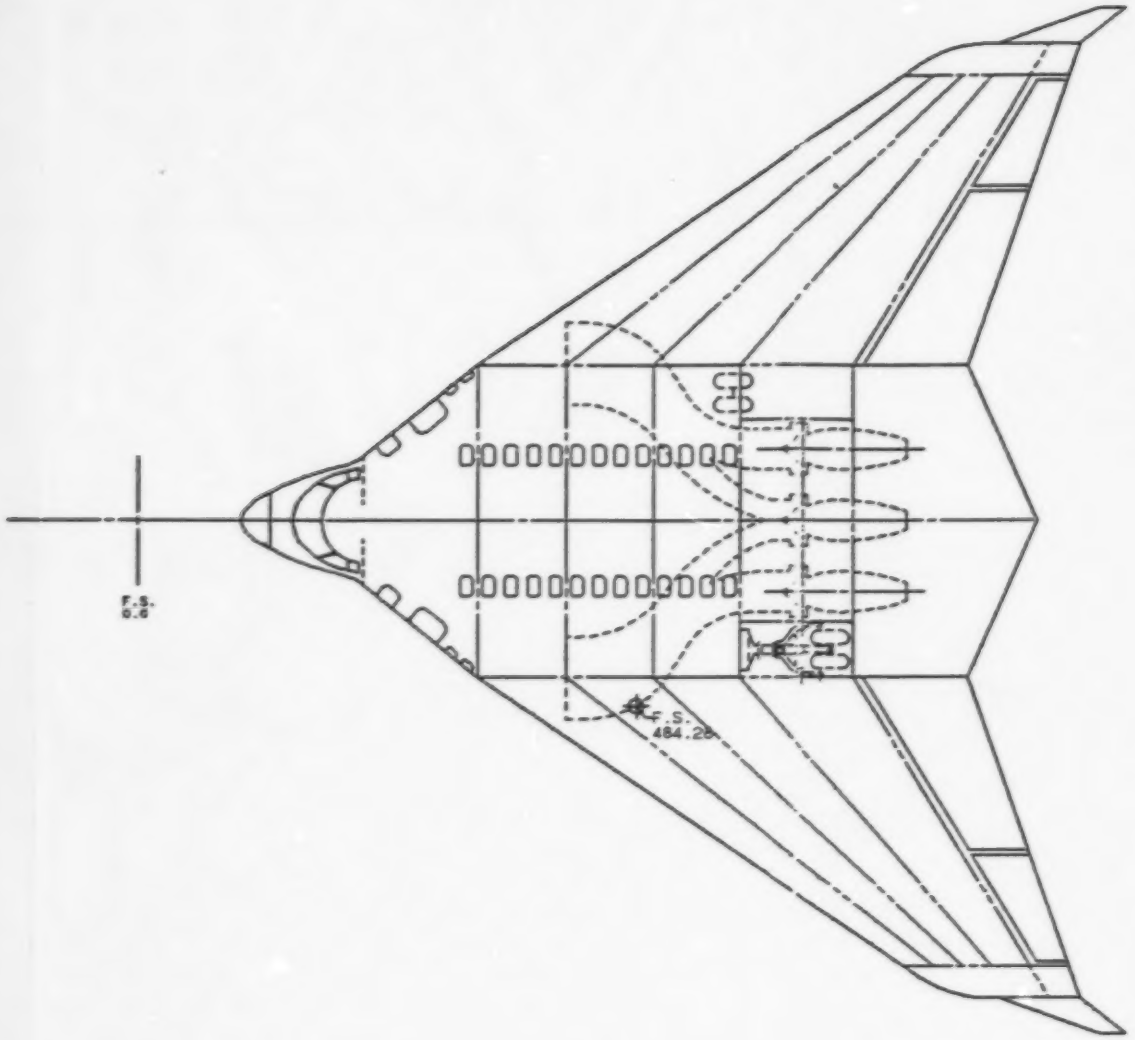
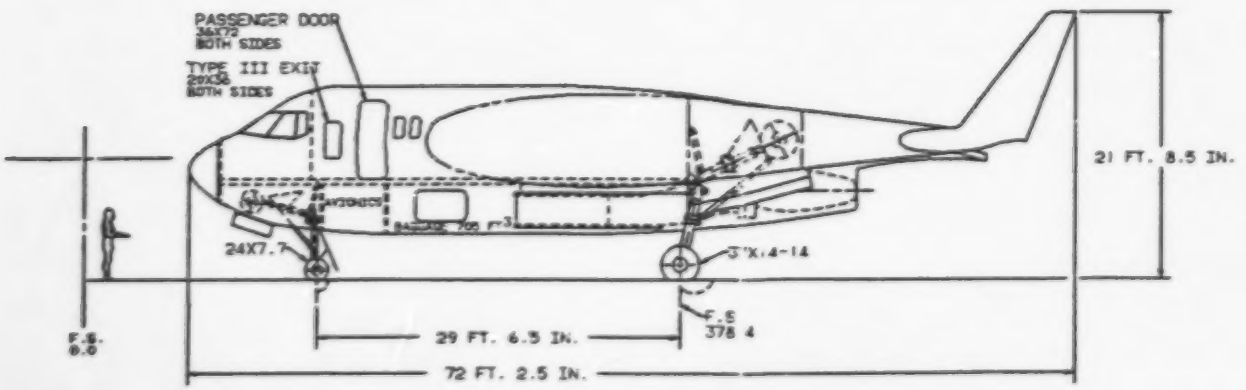


FIGURE 9- GENERAL ARRANGEMENT OF BLENDED WING-BO





OED WING-BODY CONFIGURATION

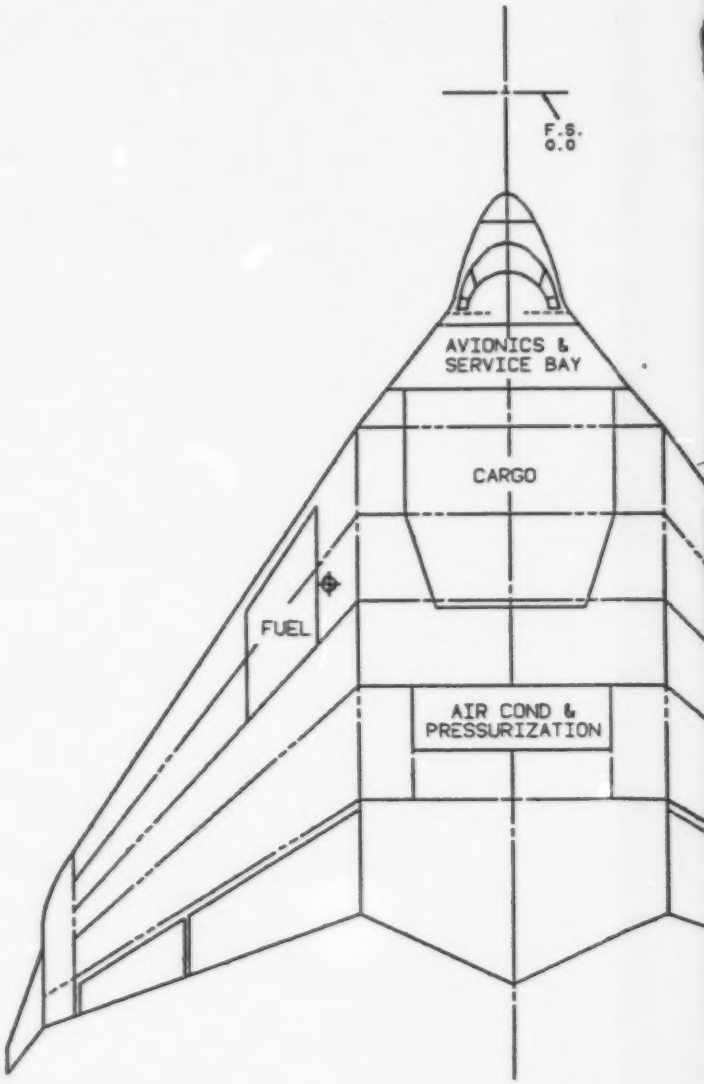
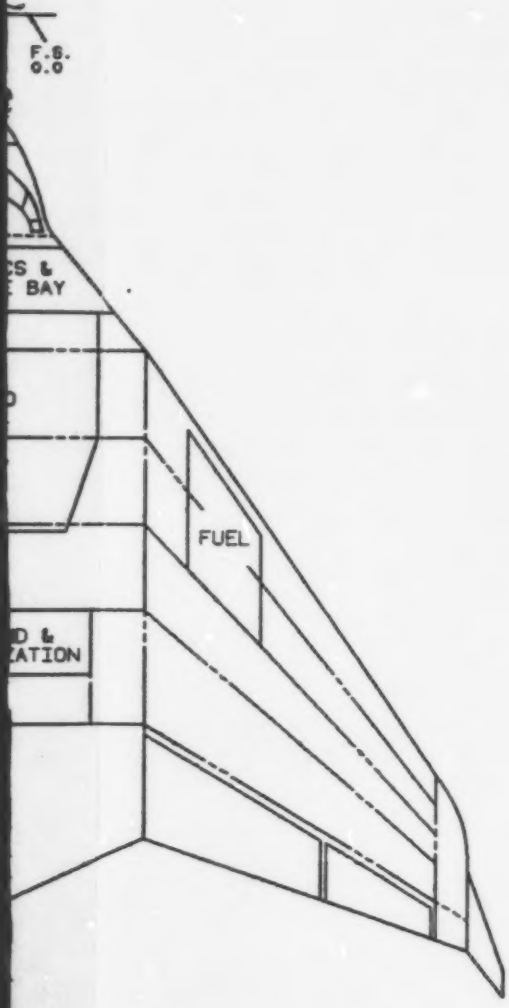


FIGURE 9- GENERAL ARRANGEMENT OF BLENDED WING-BODY



ED WING-BODY CONFIGURATION (CONT'D)

FIGURE 10 WEIGHT AND BALANCE DIAGRAM

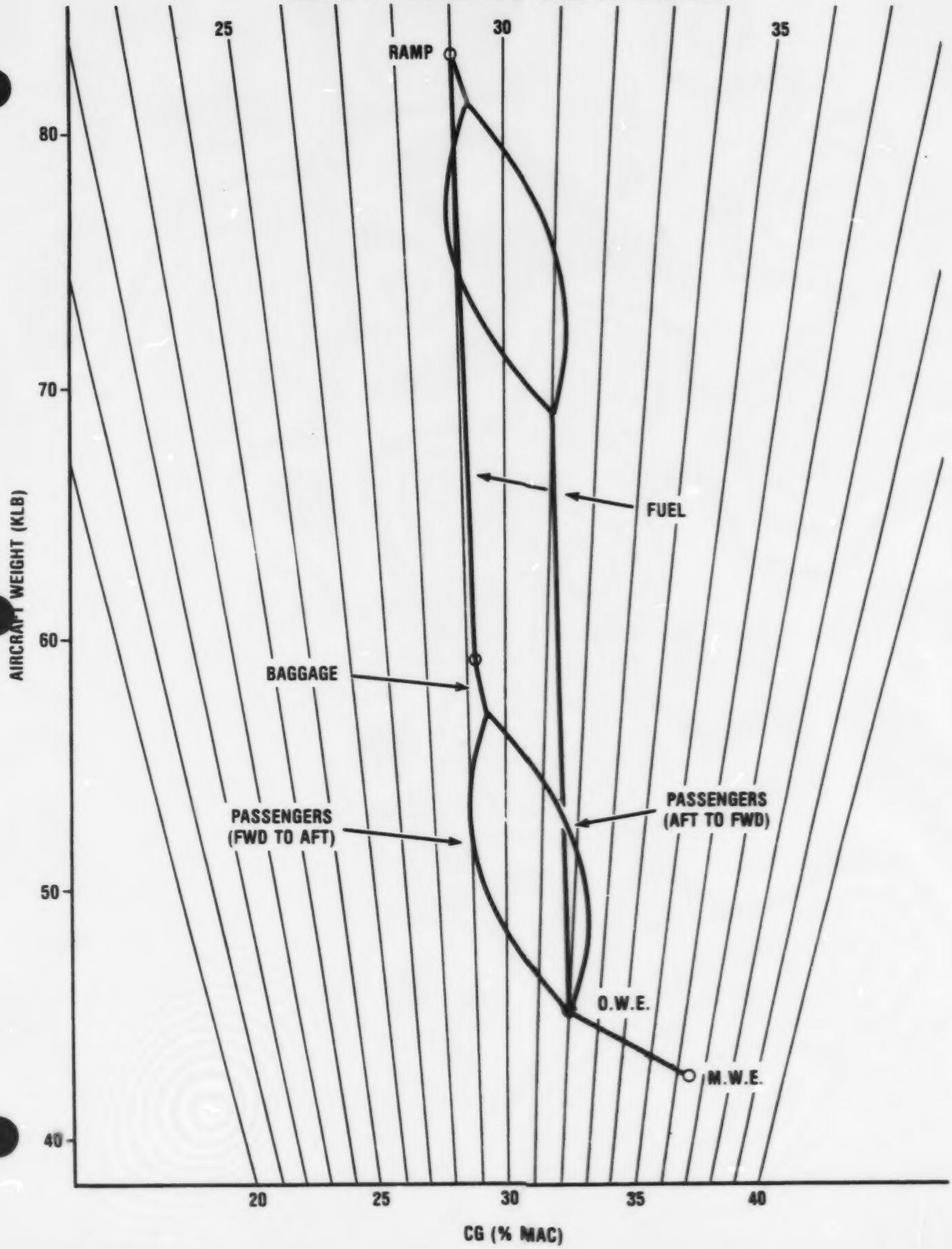


FIGURE 11
LIFT-DRAG RATIO IN CRUISE VERSUS INITIAL CRUISE ALTITUDE

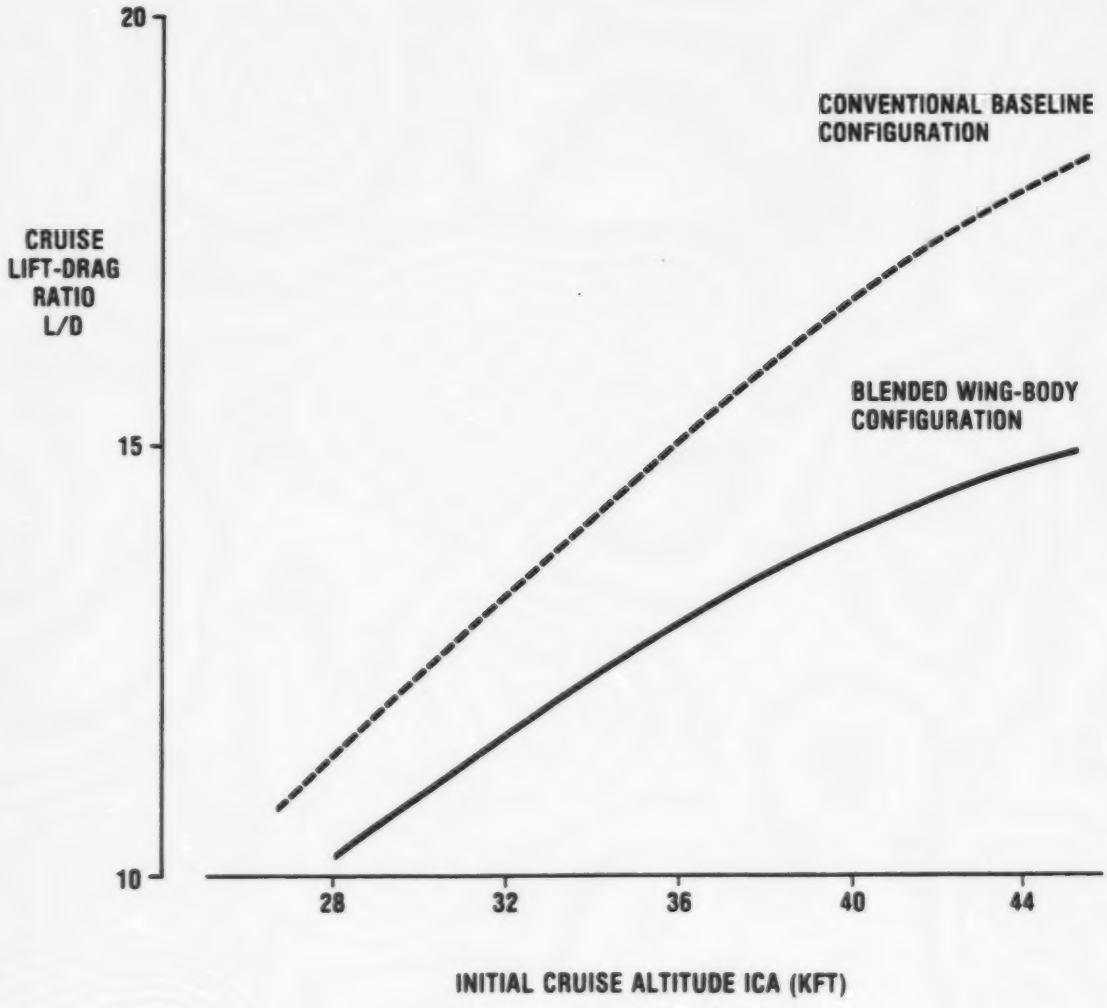


FIGURE 12

FUEL FRACTION VERSUS INITIAL CRUISE ALTITUDE

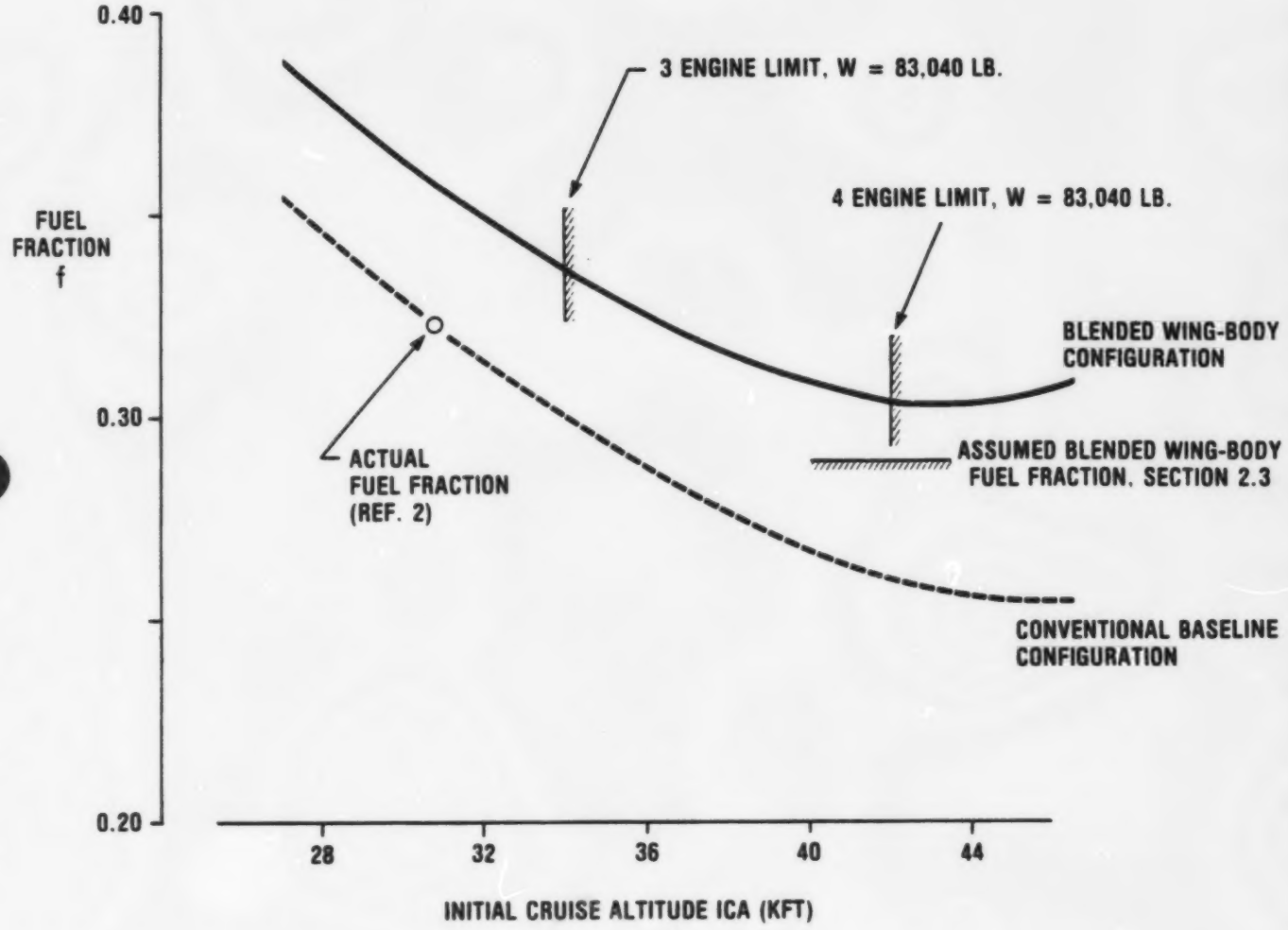


FIGURE 13

DIRECT OPERATING COST PARAMETER VERSUS INITIAL CRUISE ALTITUDE

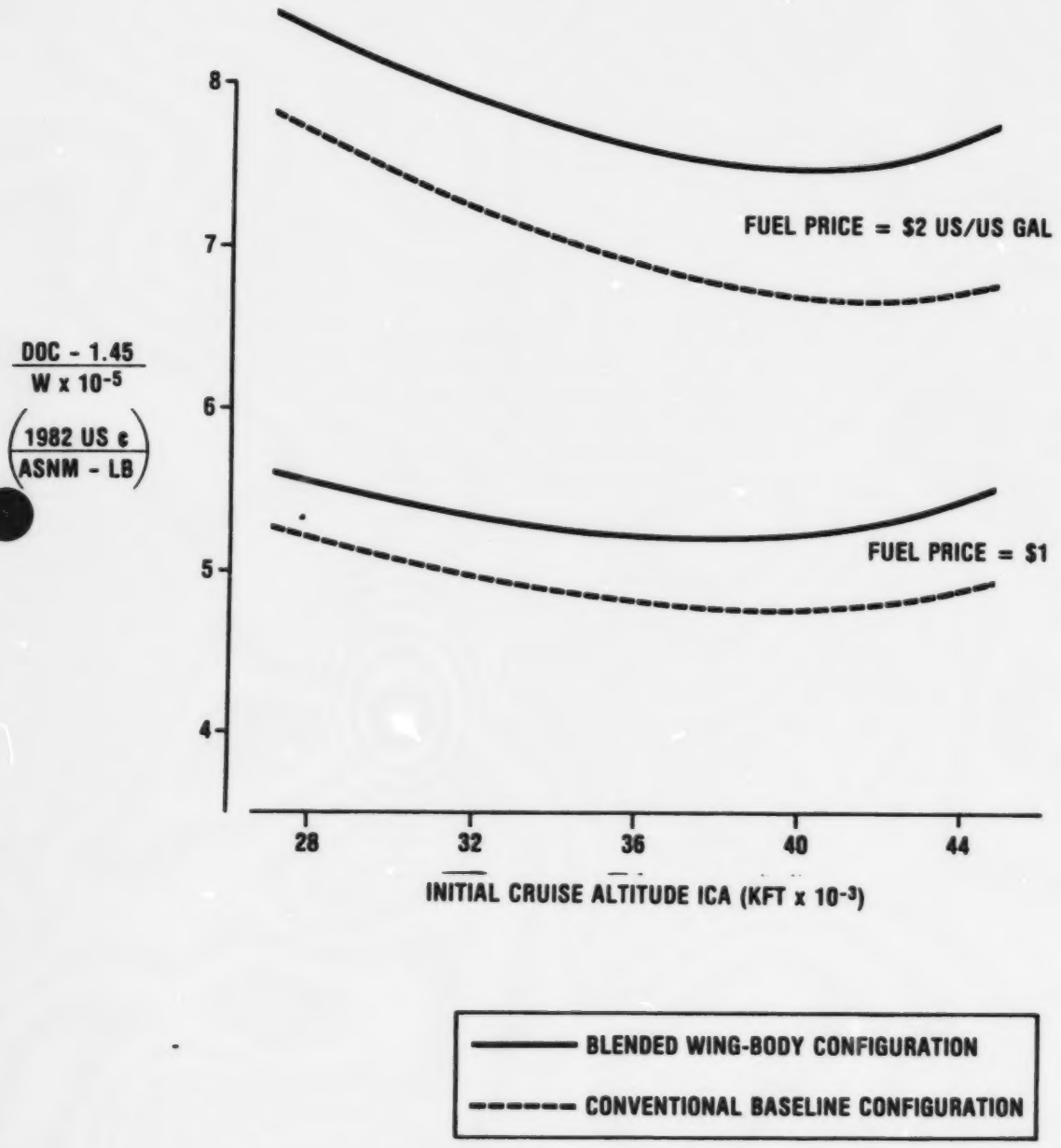
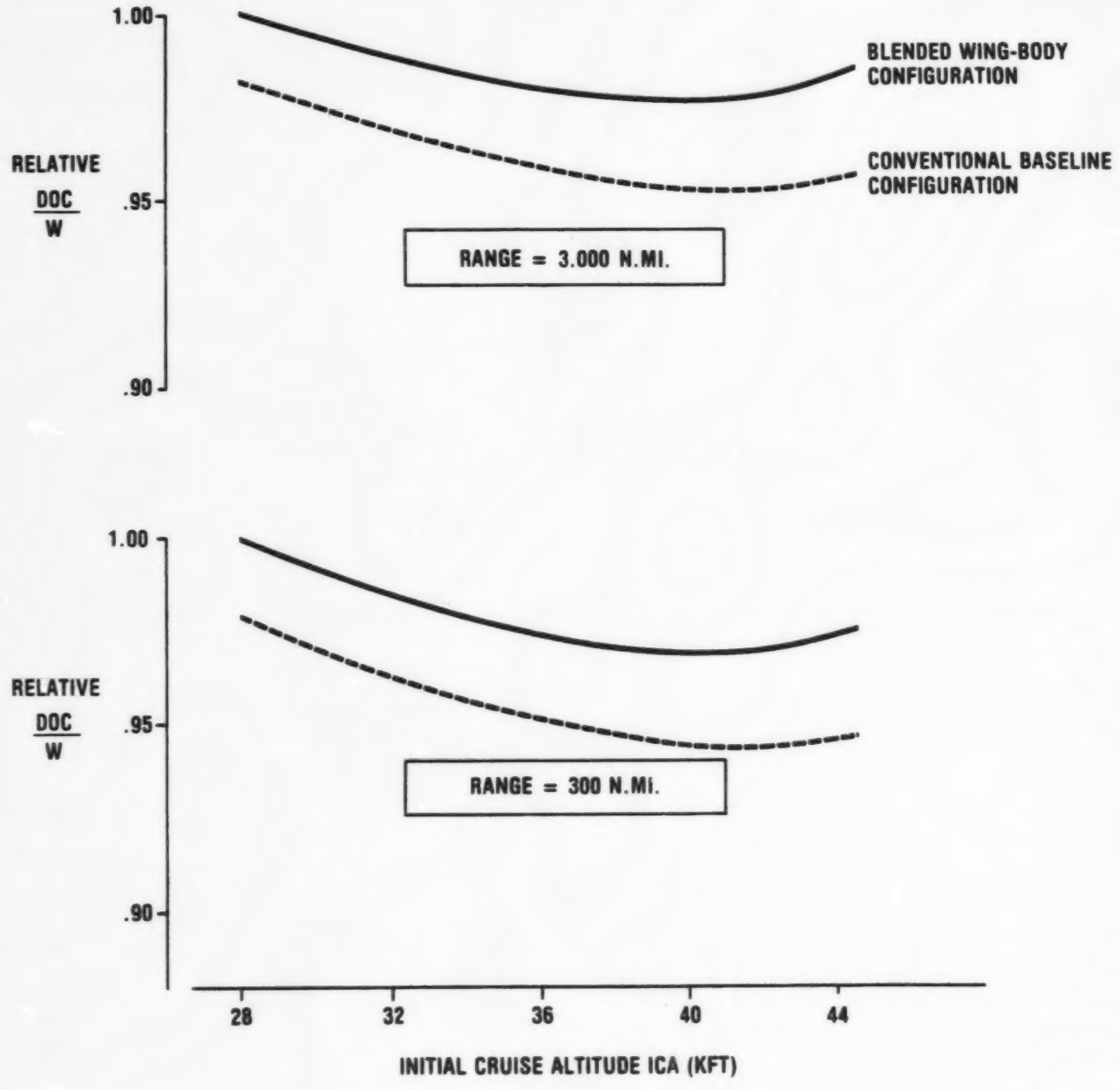


FIGURE 14

RELATIVE DIRECT OPERATING COST PER POUND OF MTOW FOR DIFFERENT RANGES



SUBJECT
AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

APPENDIX - WING PLANFORM TRADE-OFF METHOD

1. Assume a required all-out range of 3000 nm in a Mach 0.80 cruise-climb with CF-34 type powerplants.

2. Pick $C_L \rightarrow \frac{W}{\delta S} = 1481\ M^2 C_L$

3. Pick A, $\Lambda \rightarrow \frac{t}{c}$ for $C_{D_W} = 0.0020$

4. Pick $\lambda \rightarrow$ choose S for sufficient passenger cabin area.

5. Assume initial cruise altitude (ICA) $\rightarrow$ compute C_{D_o} as a function of $\frac{t}{c}$, Reynolds number, Mach number.

6. Compute $C_D, \frac{L}{D}, M\frac{L}{D}, \left(\frac{T}{\delta S}\right) = 1481\ M^2\ C_D$; then

$$\left(\frac{T}{W}\right)_{cr} = \left(\frac{T}{\delta S}\right) / \left(\frac{W}{\delta S}\right)$$

7. Compute $\cancel{S} = 1 - e^{-R/B}$, $R = 3000$ nm
$B = \frac{V}{SFC}\ \frac{L}{D}$

8. Estimate MWE $\rightarrow$ W = MWE + payload + operating items + fuel
= MWE + 14630 + 2622 + $\cancel{SW}$

9. Compute $\frac{W}{S} \rightarrow \delta = \left(\frac{W}{S}\right) / \left(\frac{W}{\delta S}\right) \rightarrow$ ICA; if not equal to assumed ICA, go to Step 5.

10. Compute $\frac{T}{W} = \frac{I}{g} \cdot \left(\frac{T}{W}\right)_{cr}$

11. Repeat for range of C_L

12. Repeat for range of A

13. Repeat for range of Λ

SUBJECT AN INVESTIGATION OF THE FEASIBILITY OF AN ALL-WING PASSENGER TRANSPORT

DISTRIBUTION

R.J. Ross	738-1
J.K. Turek	738-1
A.M. Ferrey	738-1
T.J. Hughes	785-1
A.A. Powell	785-1
J.A. Taylor	735-1
E. Aubrey	738-1
O.E. Michaelsen	735-1
J.N. Perkins	785-1
Advanced Design File (3)	785-1
W.H.D. Hanchet, Transport Canada	
c/o L. Massé (4)	608-1